Presentation to Brookhaven Workshop 9th and 10th May 2007

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Early WAGR Decommissioning Work

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WAGR Decommissioning Development work and preliminary operations

- The first part of the presentation covers the development up to the time that Magnox Electric bid for and won the contract for Dismantling Operations in1996 and developed equipment was handed over.

WAGR General data

- Work Started on building the WAGR 1958
- First at power end of 1962
- Operated at a load factor of just over 70% until April 1981
- Total irradiation 525.2 GWD
- For modelling purposes 18 years at 80MW is used
- Triangular pitch 10.75 inches
- Re-entrant design 14 ft long 15 ft diameter
- Reflectors – radial 1.8 ft, axial 2ft
- 253 channels (~197 fuelled)
- Operated at 270 psig
- Pile grade ‘A’ graphite

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WAGR Project Progression

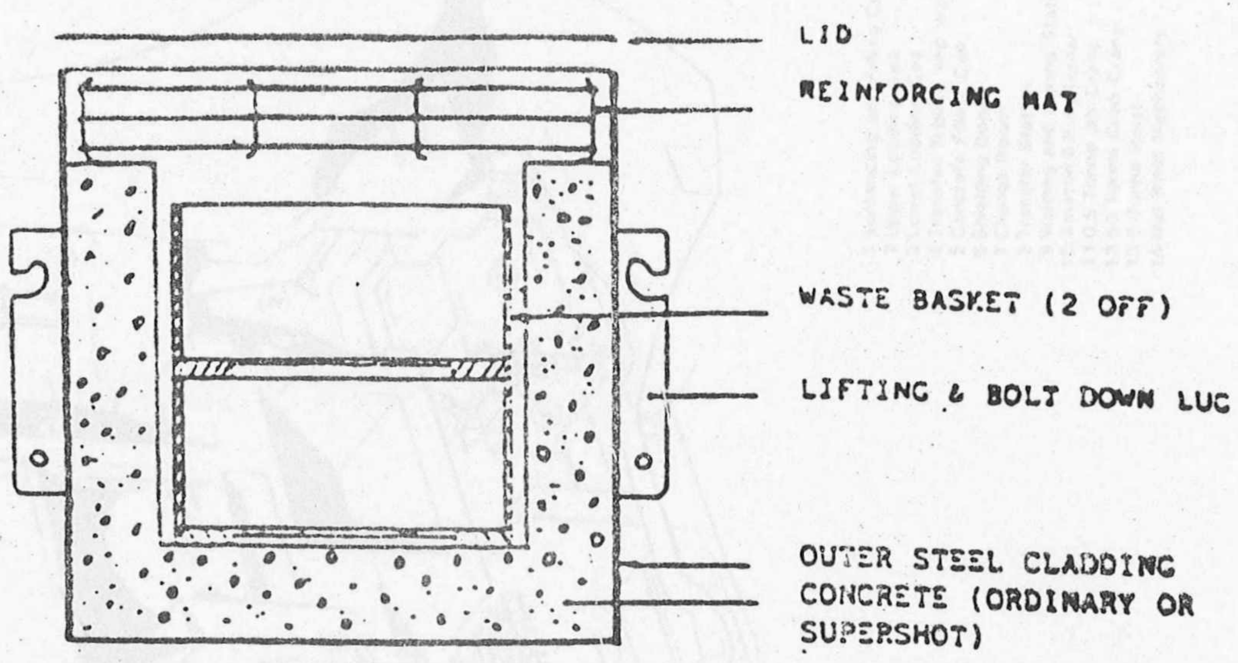
- Long before final shutdown decision taken to decommission
- It would be a demonstration project for the UK graphite reactors
- Goal would be a green field site

The Originally Envisaged Final State

WAGR Waste Container

- At the time sea disposal was seen as the best option for the arisings
- Reinforced concrete disposal boxes would be used.
- Care needed to ensure contents fully grouted with no voidage (to remove risk of implosion)
- Design of a suitable waste disposal container commenced.
- The outcome of the design with a few minor modifications is being used on the project today.

WAGR Early Concrete Box Design



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WAGR Concrete Box Design

Box sizes

	L	W	H	
Box outer	243.5	220.7	219.7	cm
Box inner	195.5	172.7	171.7	cm

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WAGR ILW Store

- The London Convention in 1972 embargoed any form of waste disposal at sea.
- No ILW repository would be available on the project timescale hence local temporary storage would be required.
- An appropriate building was planned, designed and built

The WAGR site showing the turbine hall, the stringer dismantling building and the Waste box store

Development of a Decommissioning Method

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Radiation levels

- Essential to know extent to which remote operations are required
- Knowledge of reactor component activities needed for this
- Also needed for sentencing of waste arisings for transport and ultimate disposal
- Initial simplistic calculations using one dimensional neutron diffusion calculations showed that core and pressure vessel contents from the lower neutron shield onwards would require totally remote working.
- Internal radiation measurements were made but until reactor shutdown and de-fuelled these would not represent the decommissioning picture

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Early Planning

- Initial thoughts were to let a single contract for the whole decommissioning task.
- Cost prohibitive due to the unknowns and risk contingencies.
- UKAEA decided to look at options for decommissioning, select one and let several smaller packages of work, managing the interfaces themselves.

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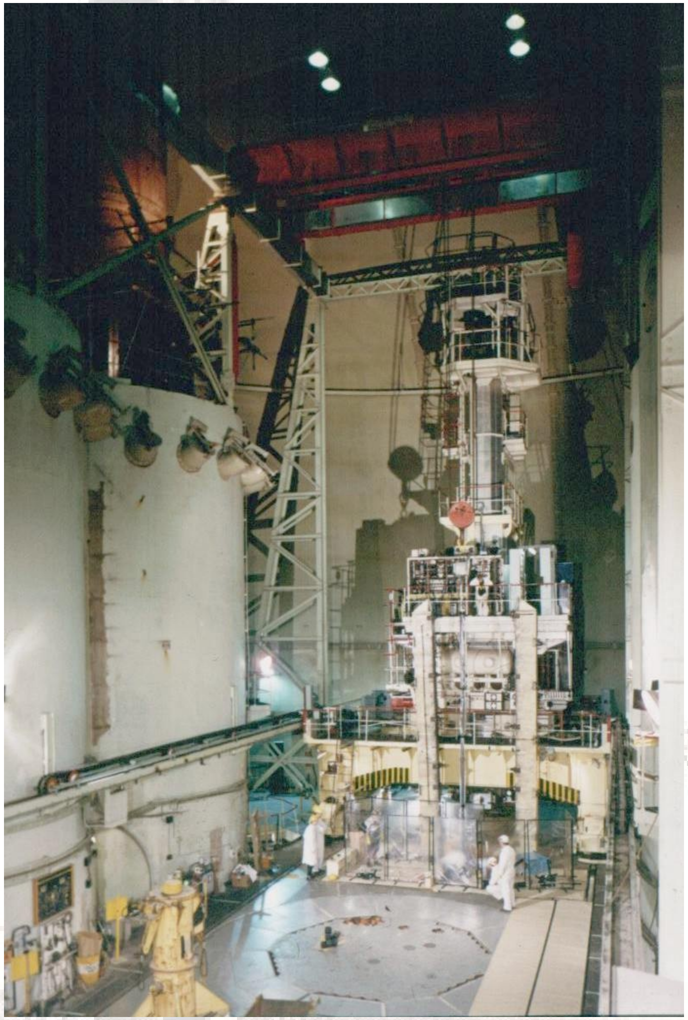
Early Planning Continued

- The reactor is actually quite small – core diameter 15 ft.
- As regards manipulative capability the options at the time were either to use a number of specific tasks machines for each decommissioning campaign/task or to develop a general purpose dextrous manipulator with ample reach to cover all regions of the vault and the ability carry out all foreseeable tasks using only small adapted hand tools and cutting torches.
- Because the reactor components mostly comprise discrete blocks, eg the neutron shield, the core and reflectors and the thermal shield, such a manipulator with a good hoist system was deemed sufficient.

The WAGR Pile Cap During Operation



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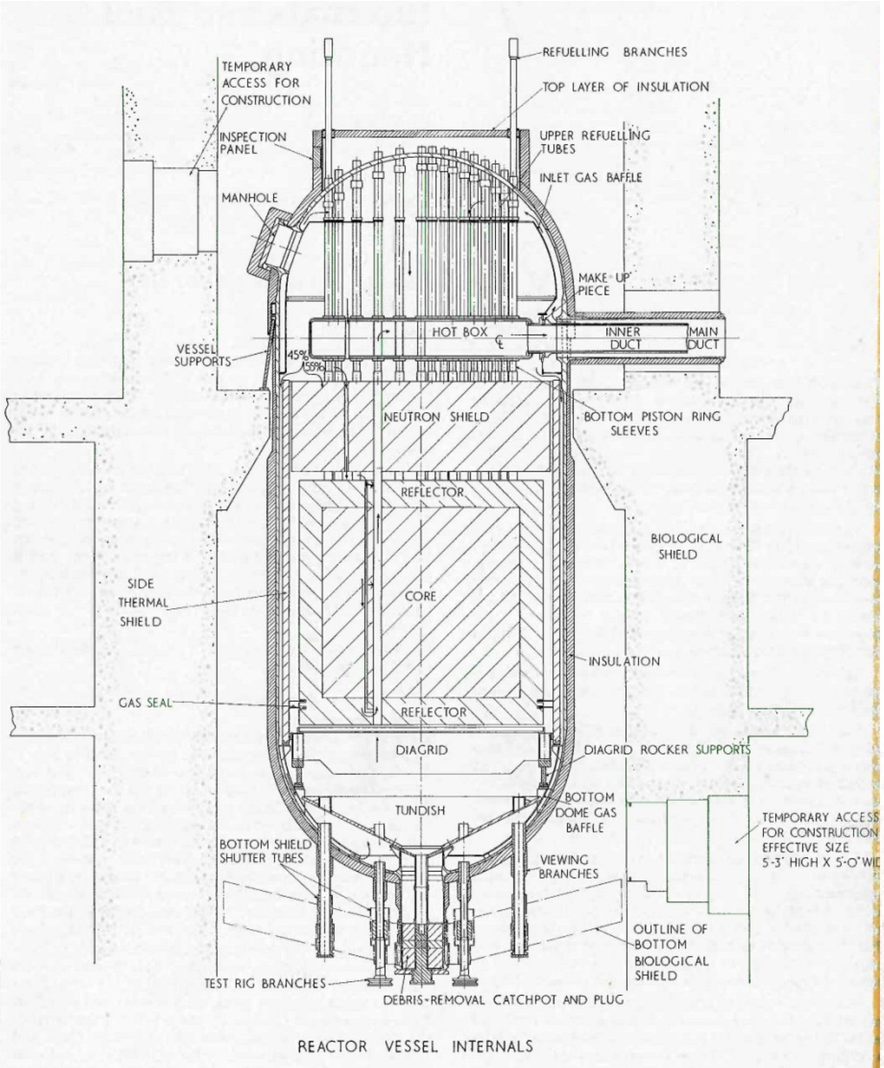
Schematic of the reactor pressure vessel and its internals and the surrounding bioshield



1—*General arrangement of reactor internals*

Chosen Option

- Use as much of the existing building as possible adding shielding and modifying structures as necessary to provide dismantling, waste handling and processing capabilities.
- Work from the top downwards removing the top bioshield and pressure vessel top dome and installing 'Remote Dismantling Machine' (RDM) in its place.
- The RDM would deploy a manipulative capability to all regions within the reactor containment.
- The manipulative capability would only have to handle low reaction forces – 35 kg was adopted as the requirement

Continued

Chosen Option

- The main dismantling device would be a propane cutting torch, with powder injection for stainless steel and composite structures

- A hoist system was needed in the reactor vault with the ability to transfer waste from the vault to a cell where the waste could be sentenced before being loaded into the disposal boxes.

- Facilities for maintenance of the equipment were also required

Chosen Option – Work packages

The main work packages at the time were:

- **The Remote Dismantling machine**
- **The manipulator**
- **The general vault viewing and lighting system**
- **The viewing system for manipulator operations. (On five axis boom)**
- **The waste route**
- **The data logging system**
- **The grouting/concreting plant**
- **The gas control system**
- **A wide range of grabs to meet foreseen requirements**
- **A universal remotely operable grab control system**
- **Methodology development for the various components**

The Model of the Remote Dismantling Machine (RDM)

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Work Prior to Installation Of RDM

- 1983 All fuel removed
- !983 to 1989 Operational waste (control rods, neutron shield plugs etc) cut to suitable sizes for box disposal and lifting attachments fitted. Returned to reactor for temporary storage.
- 1990 to 1992 Top biological shield biscuit lifted out and cut-up.
  - **Refuelling standpipes cut. Disposed of to LLW store**
  - **Top dome cut and removed. Disposed of to LLW store**
- 1993 to 1994 Remote dismantling machine installed

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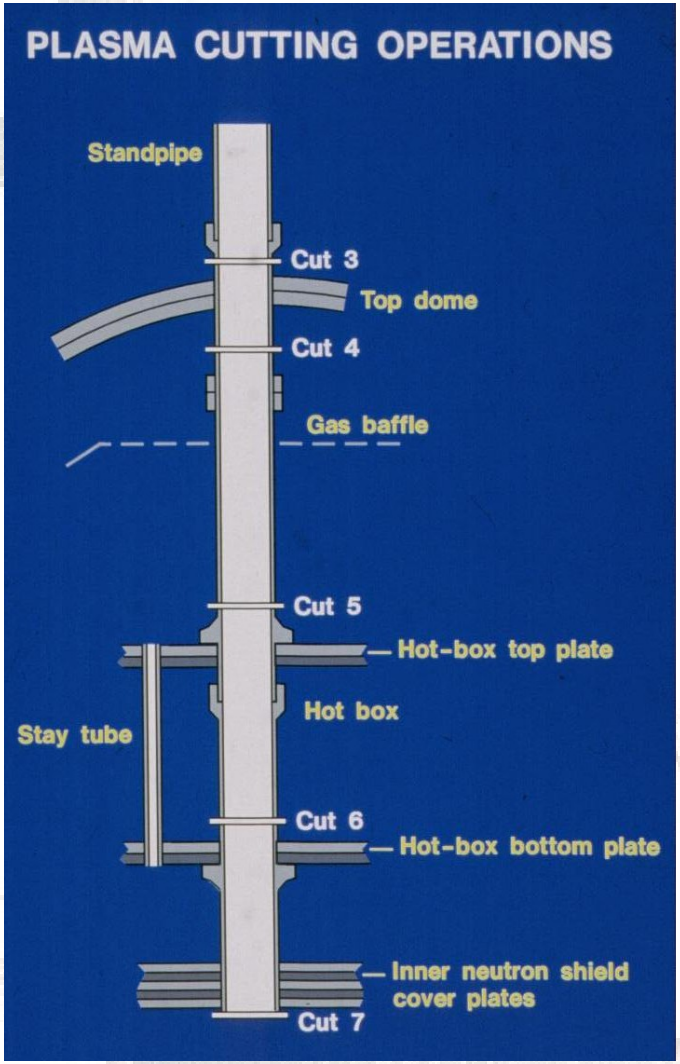
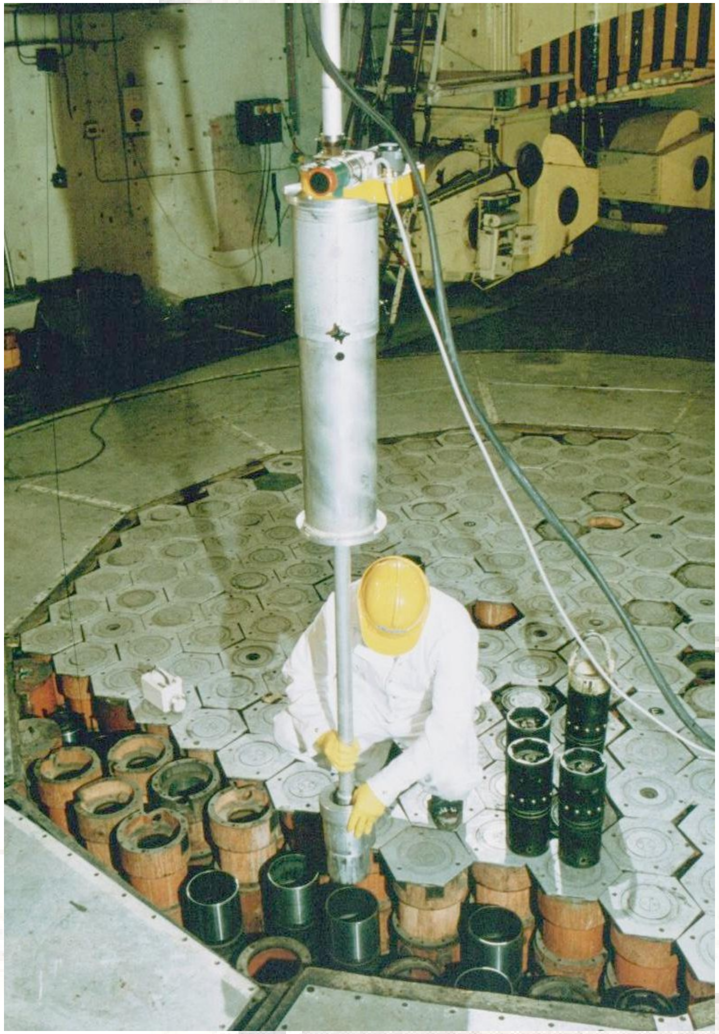
Removal of the Top Bioshield Biscuit and Top Dome

Standpipe cuts made using plasma torches



Standpipe
Pasma
Cutting



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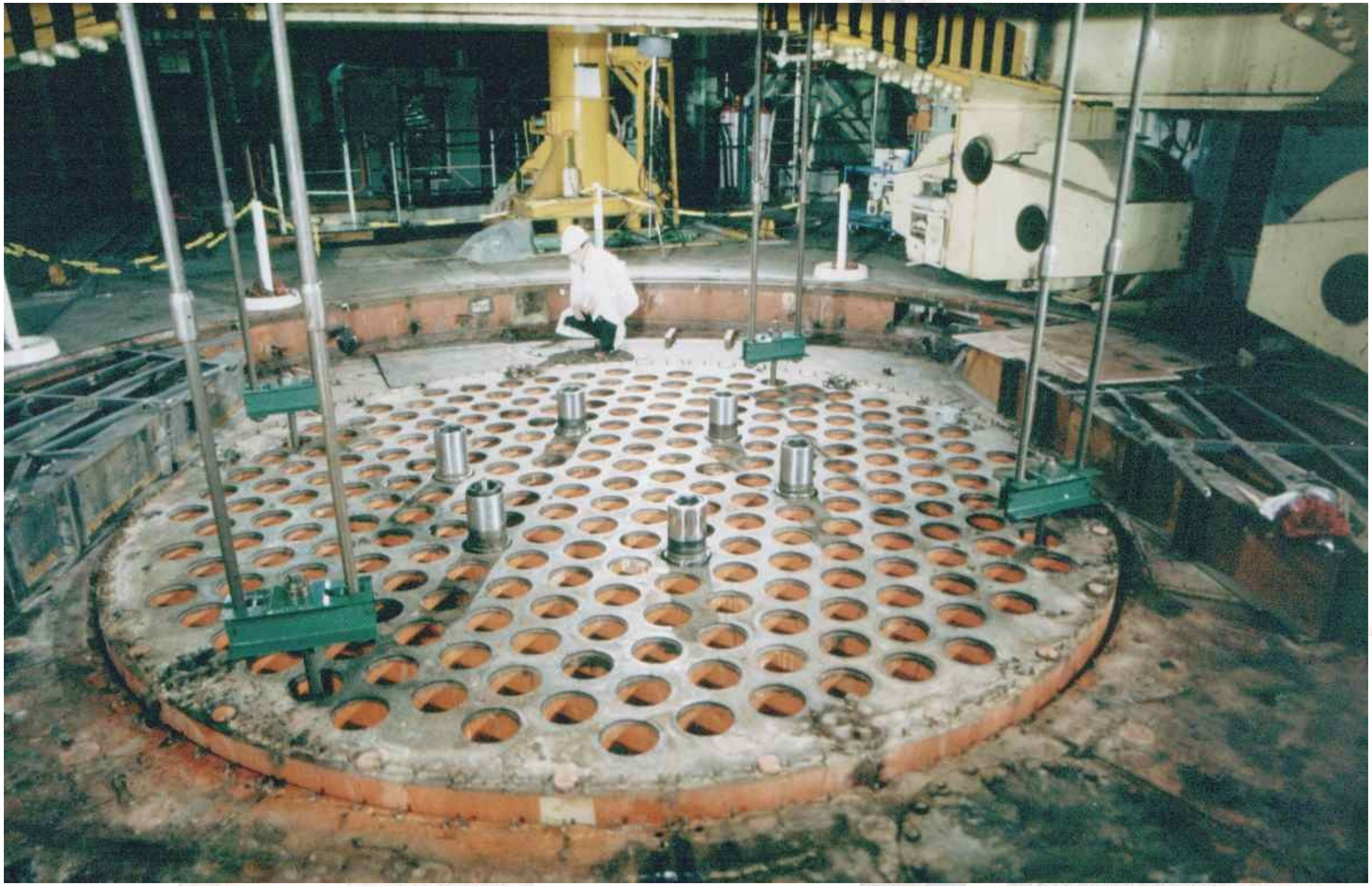
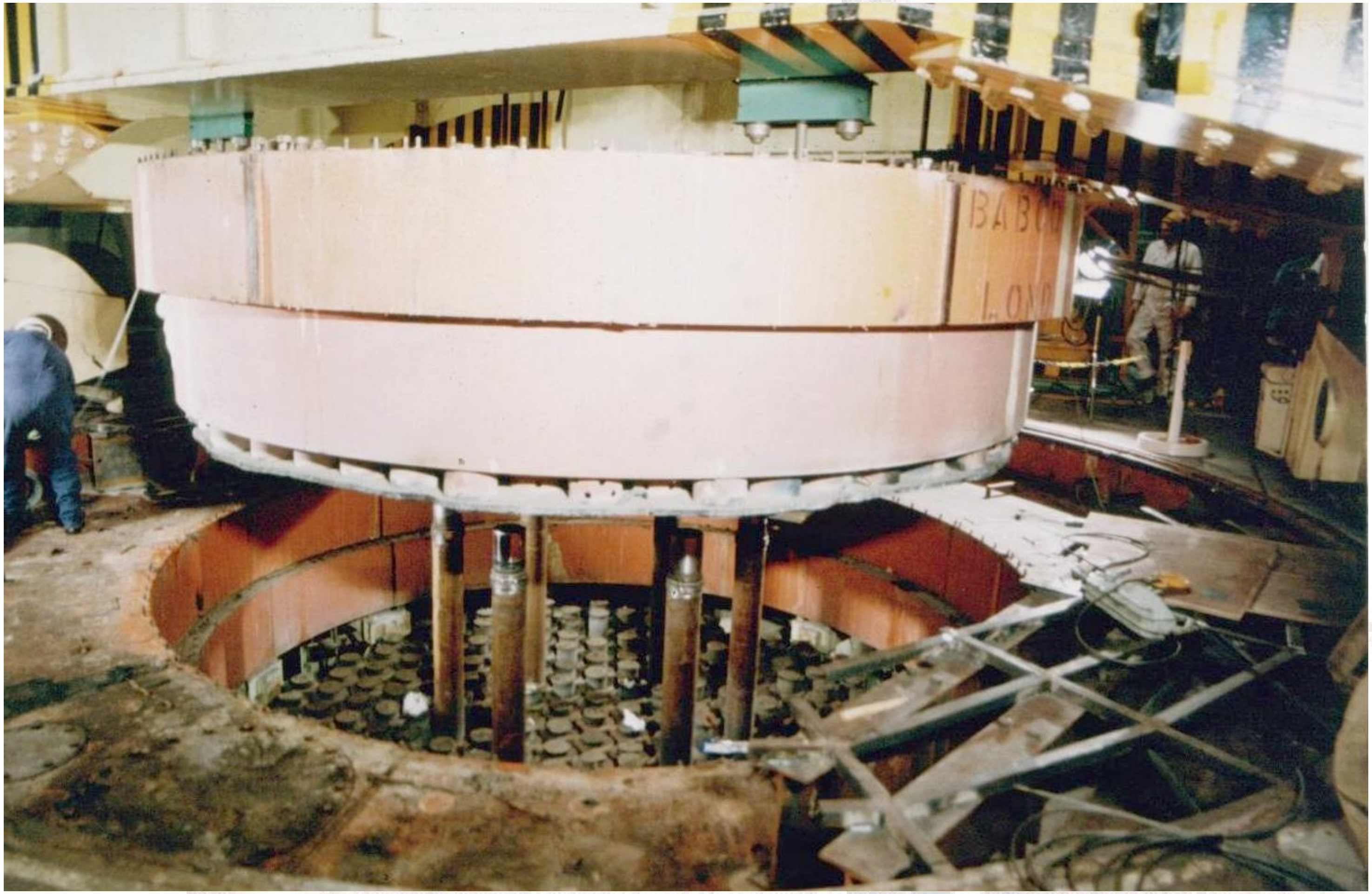


Start of the jacking out of the top bioshield biscuit



Top bioshield biscuit lifted clear using re-fuelling machine yoke

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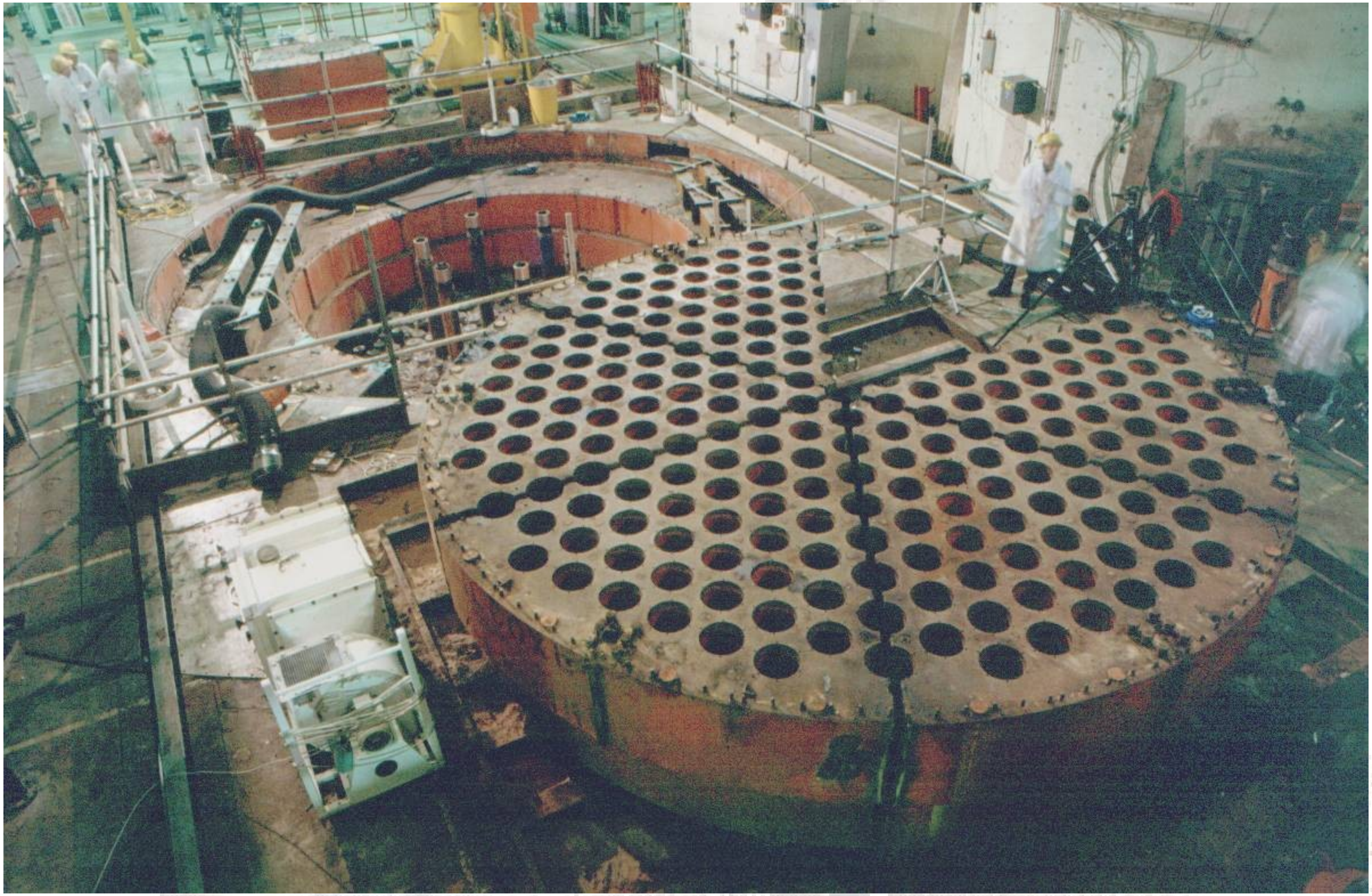

Top Bioshield Biscuit after cake Slicing with a thermic lance

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Biscuit fully removed and top dome visible

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Top dome cutting

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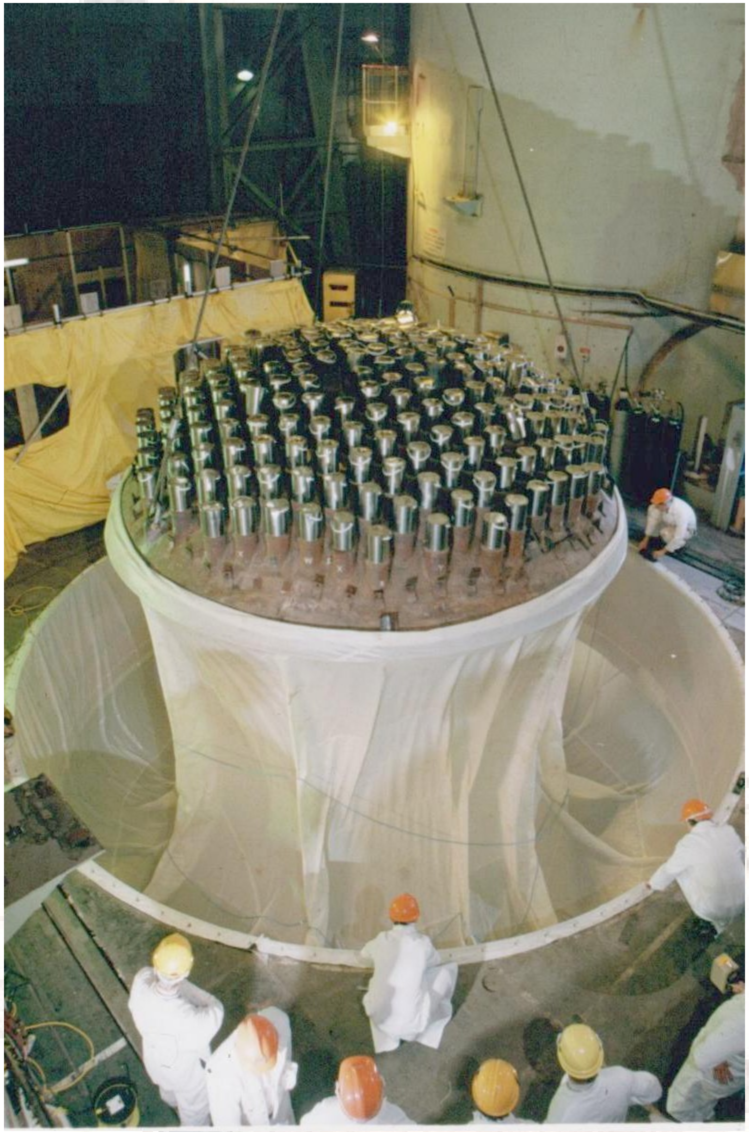
First section of top dome being lifted free. The Membrane is to preserve the integrity of the ventilation flow in the reactor vault region



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Membrane being tied off to preserve containment

The second section of the top dome being lifted free.

Installation of the RDM

The pile cap

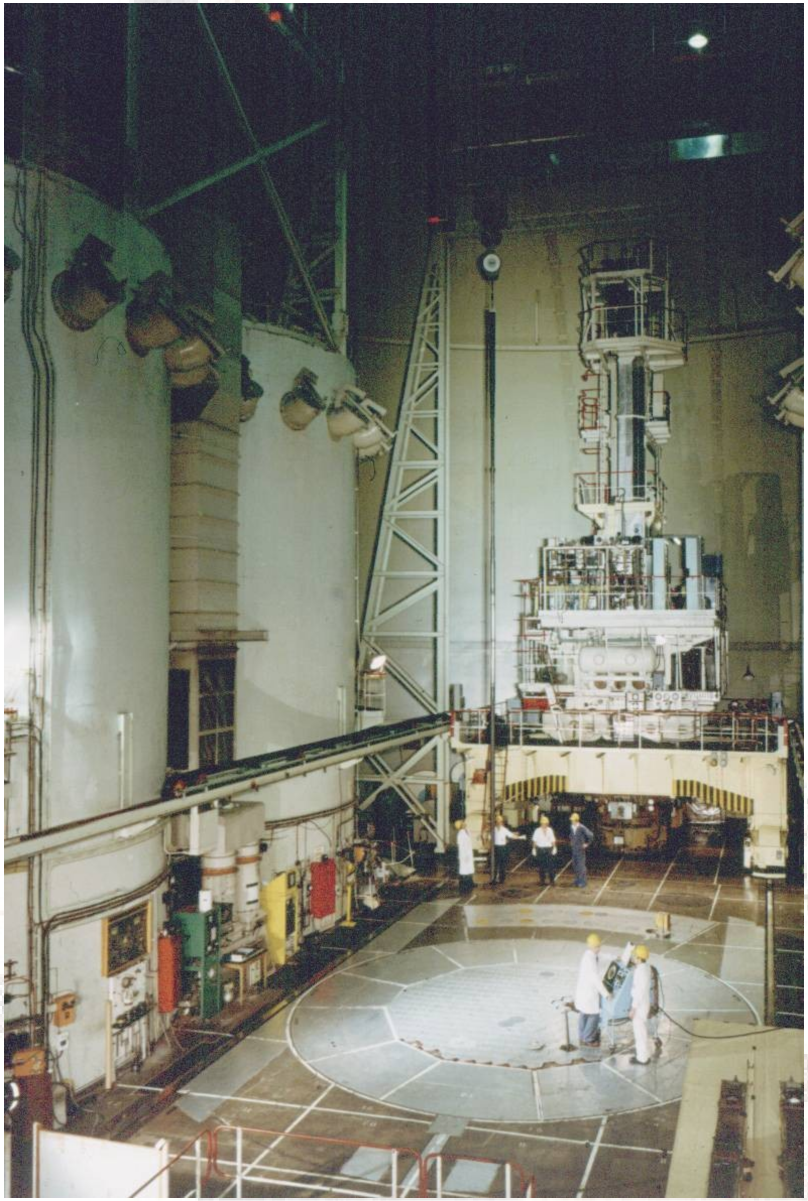

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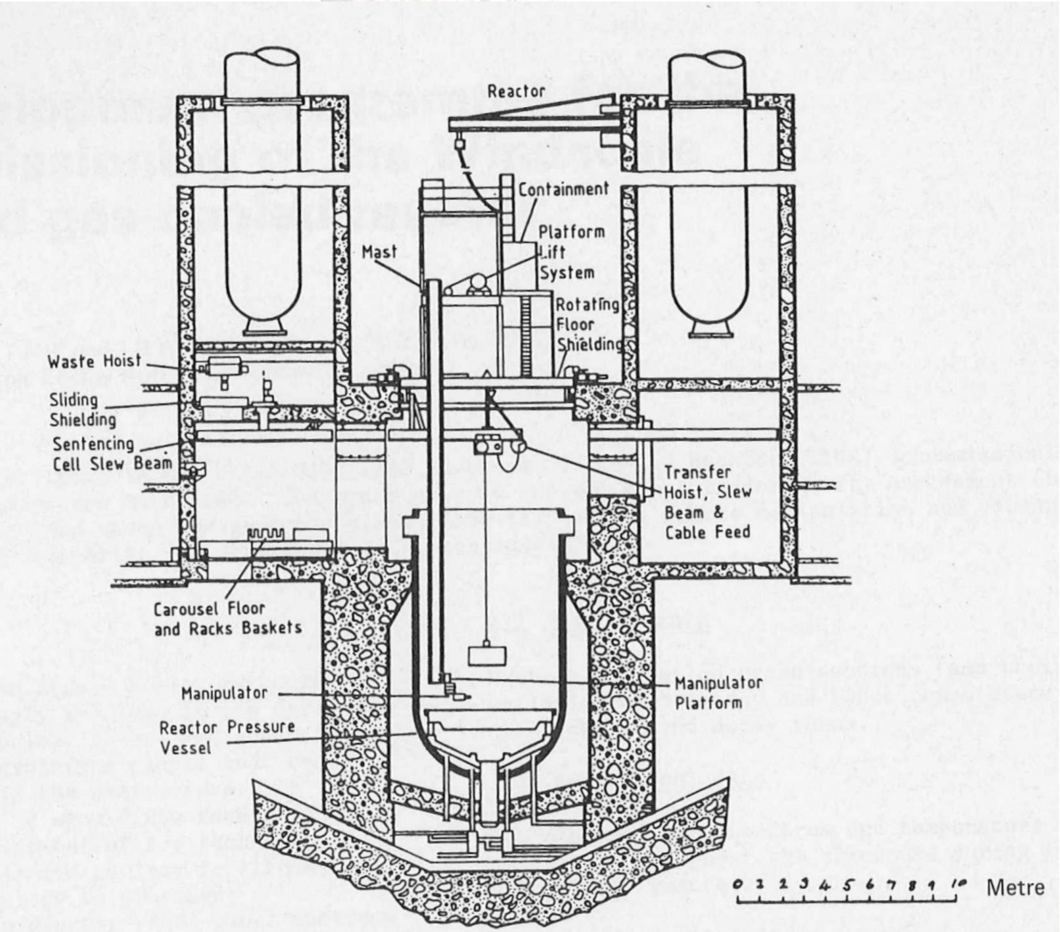
Diagram showing the main components of the RDM



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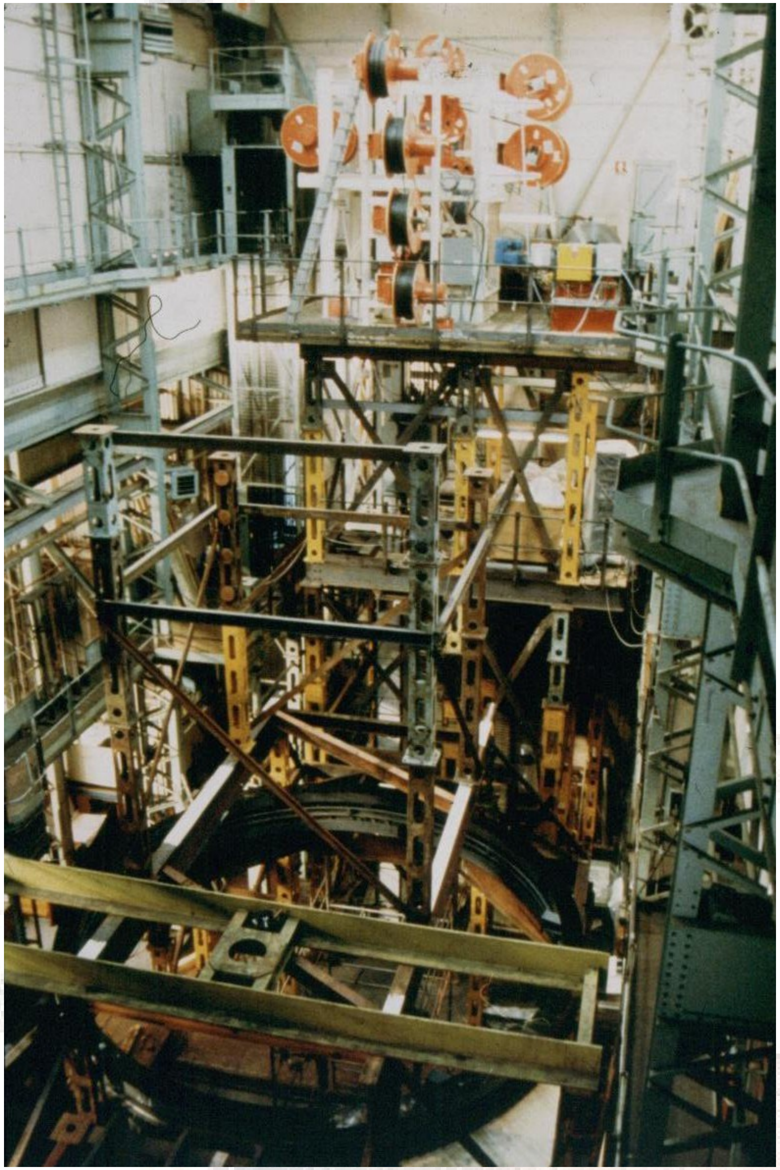
The RDM being built up over the reactor following removal of the top bisohield and the pressure vessel top dome



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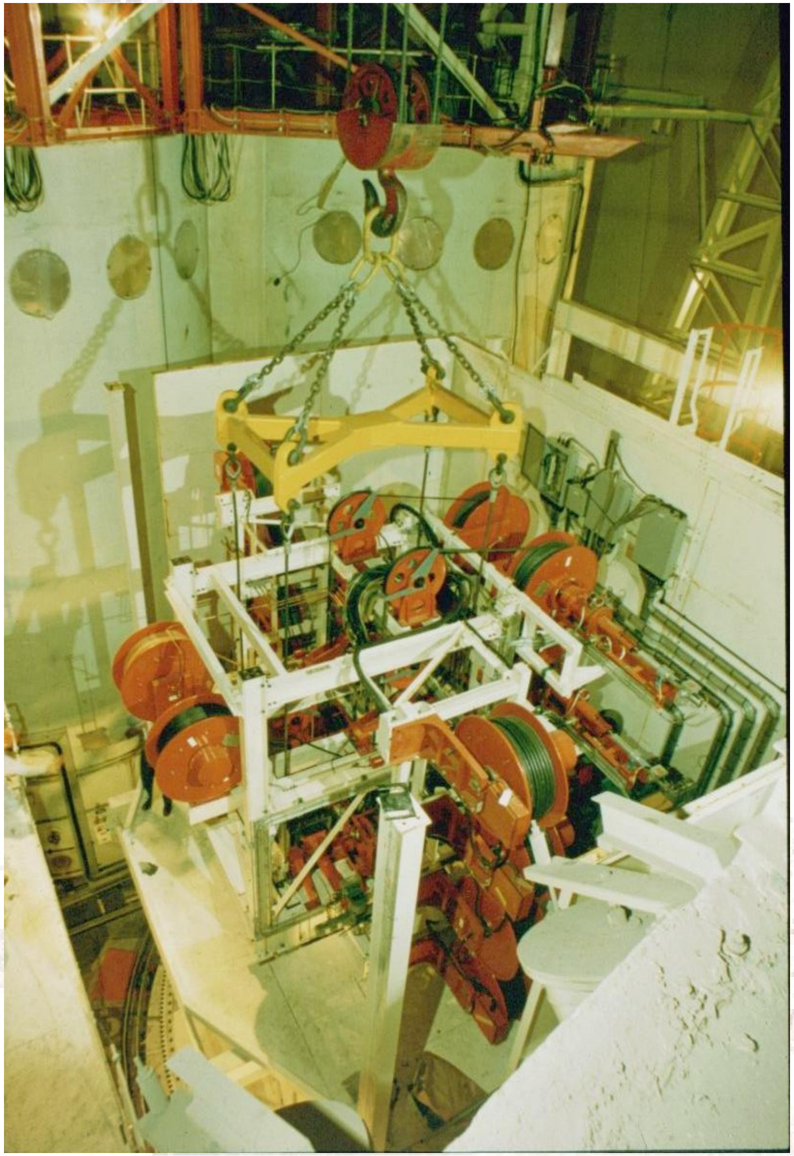
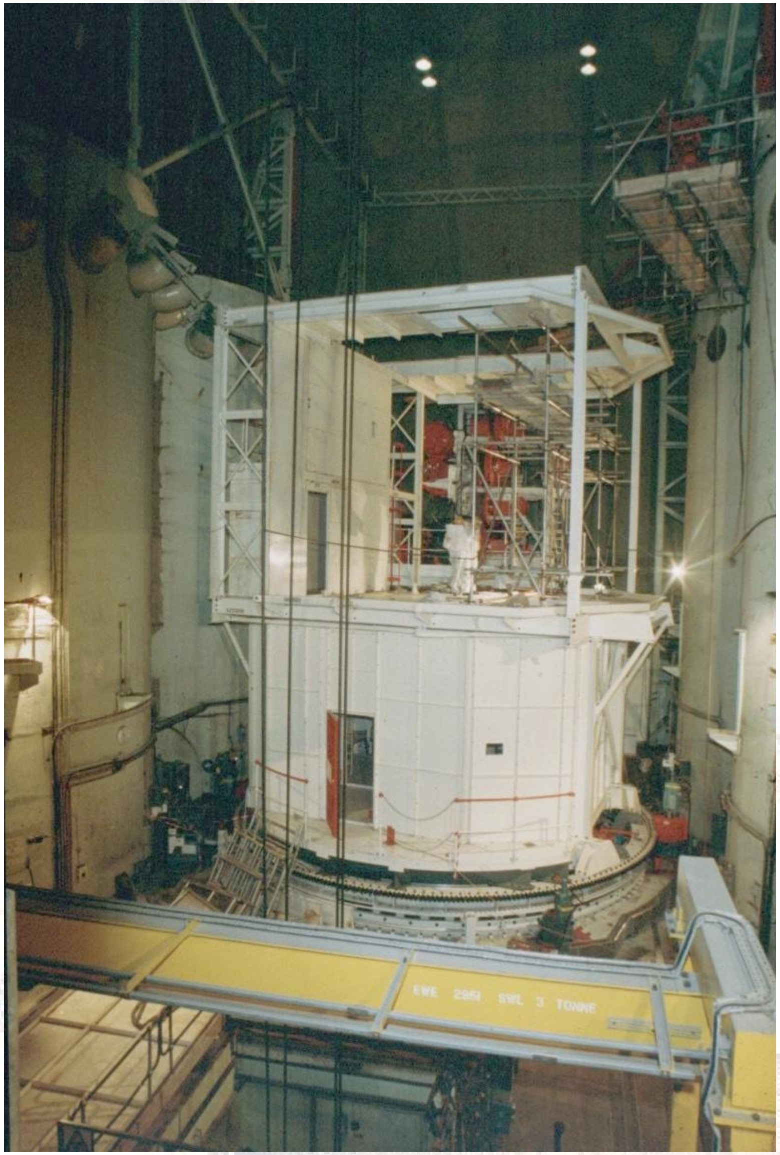
With the rotating floor shield in place the superstructure comprising the containment and the reeling drums which will provide services for the tooling on the manipulator platform are installed in their frame



The nearly complete RDM structure awaiting the addition of the cladding on the upper containment region around the reeling drums.

The cabling davit from the top of heat exchanger ‘C is still being installed. Careful cabling control is necessary to allow the RDM to rotate through just over 360 degrees.



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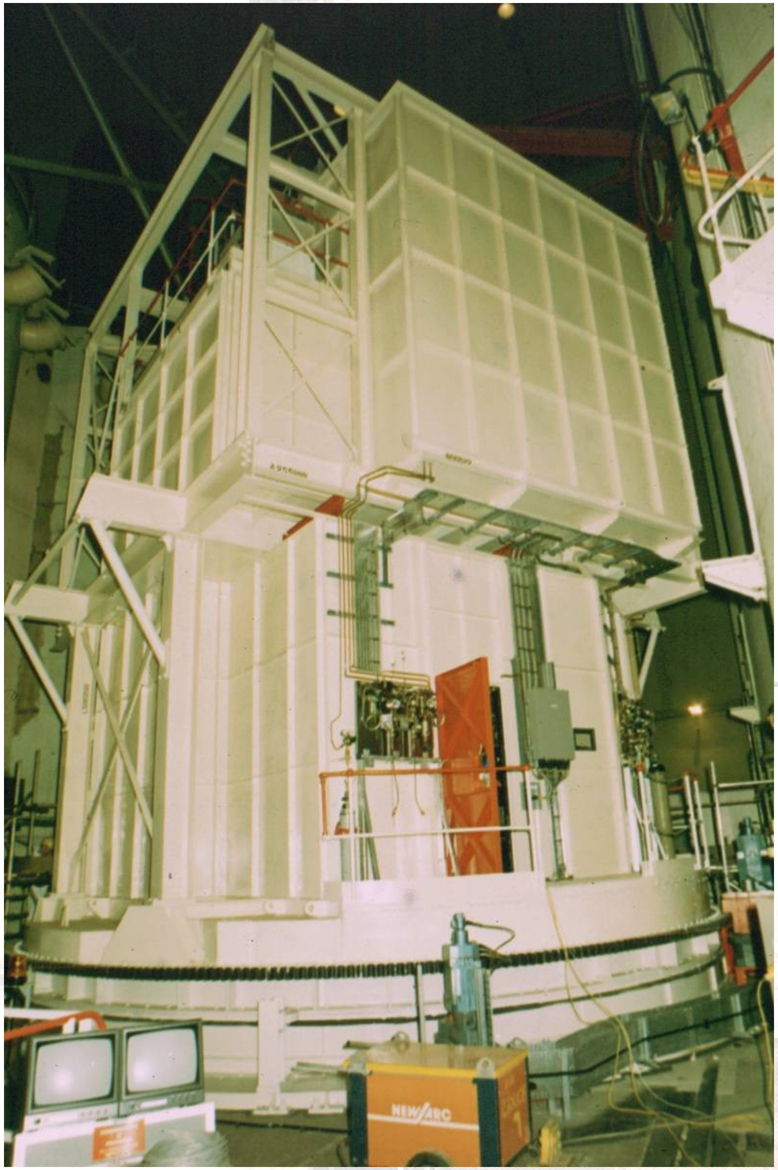
The RDM with the completed upper and lower containment structures



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The RDM main control station

The Waste Route

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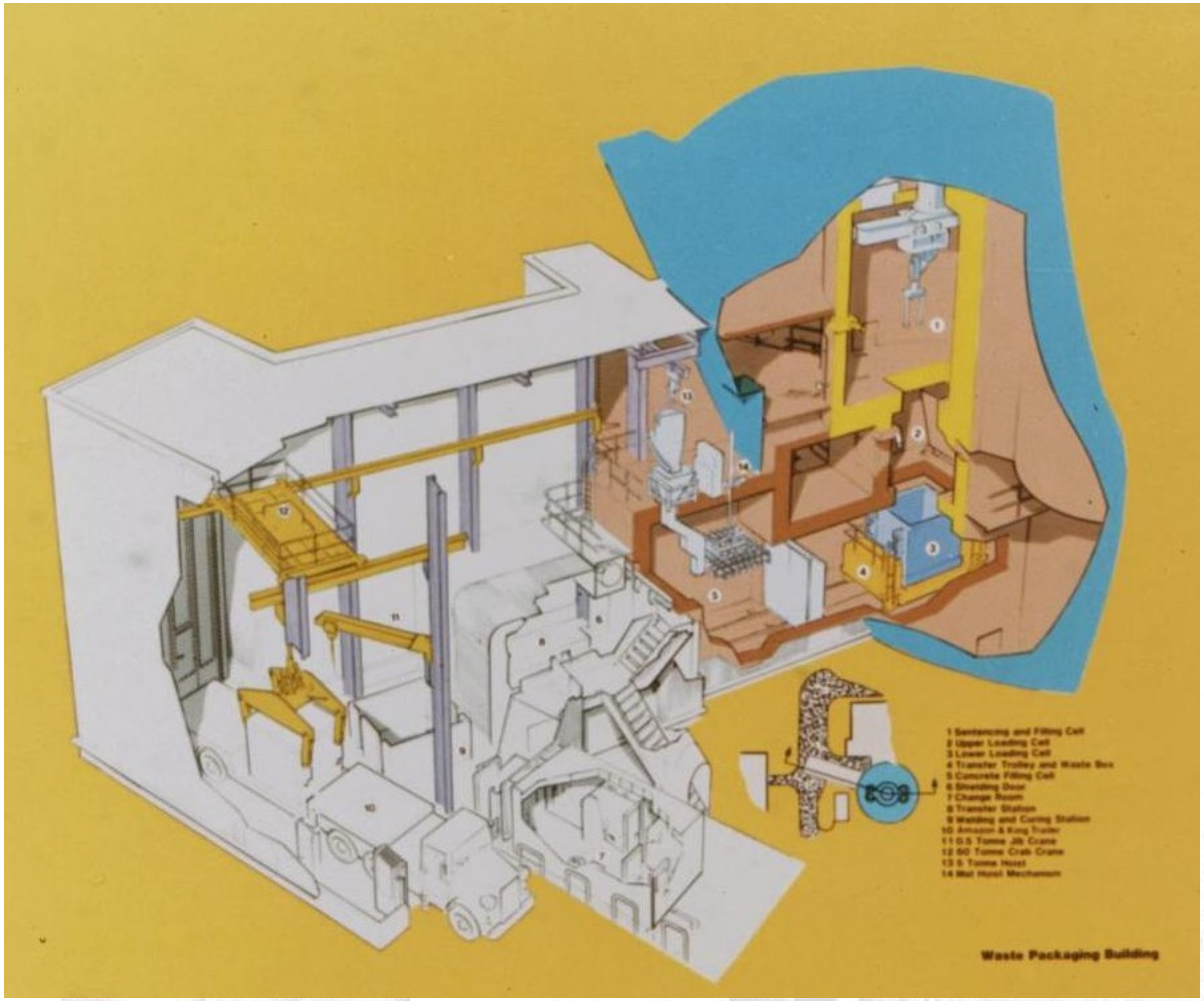

Proposed modifications/additions to the reactor building to facilitate decommissioning and provide a waste route

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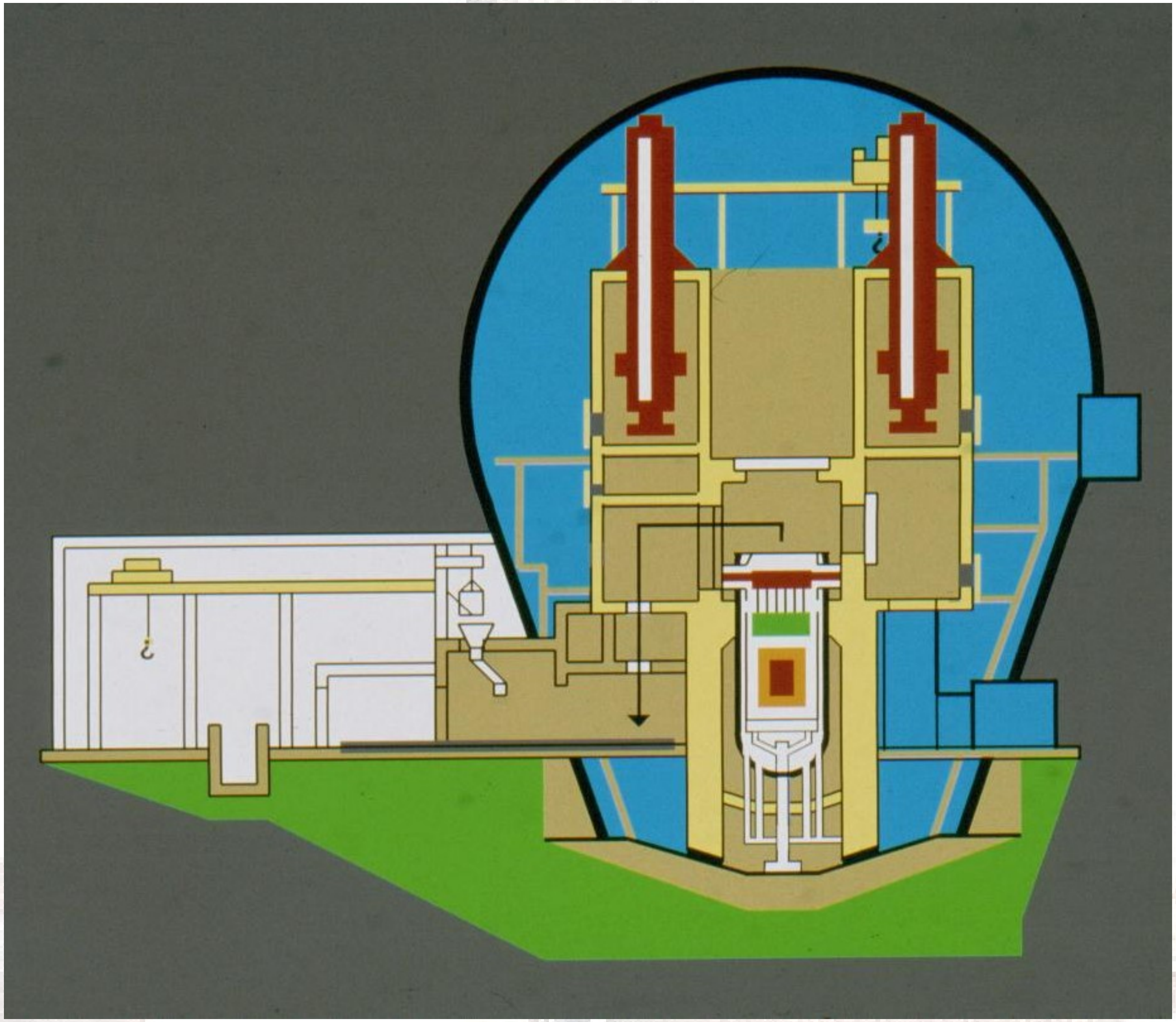
View from the Curing/weighing pit back towards the concreting cell behind which is the lower loading cell

Elevation of the WAGR and waste packaging building



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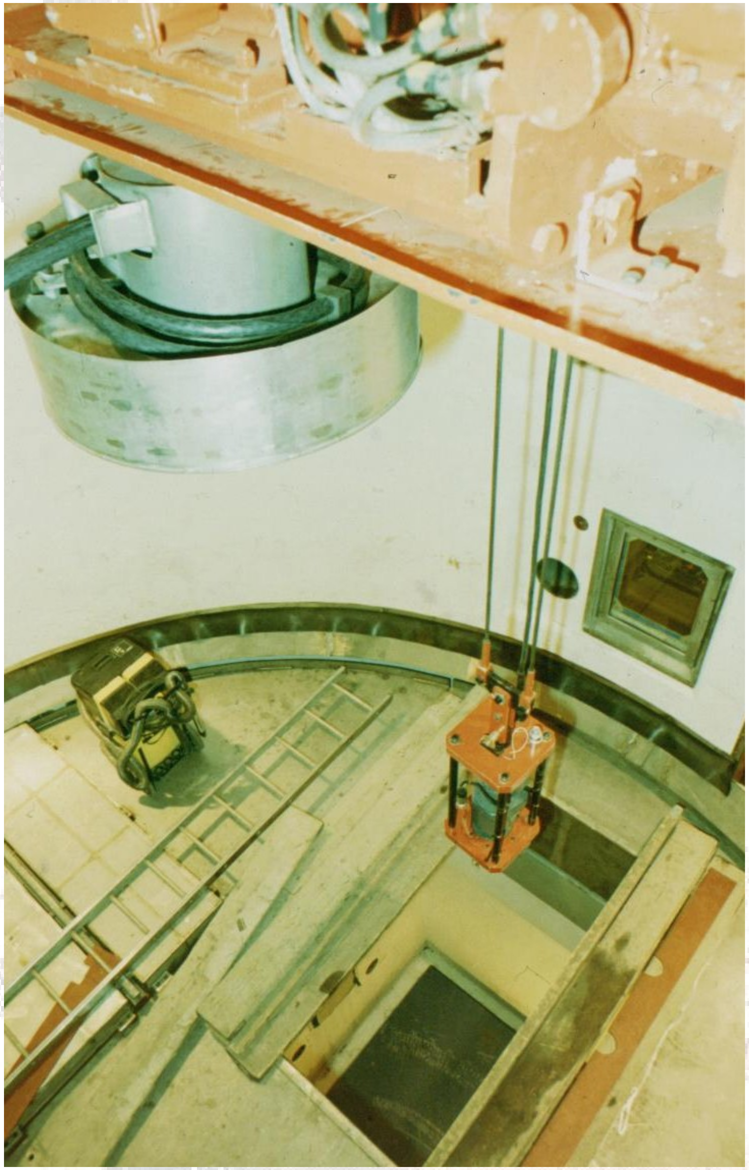
The sentencing cell

View into the sentencing cell from the 8te hoist room. The rotating floor is positioned with the vacant position over the hole leading into the upper loading cell and the lower loading cell below



The Sampling station

This is a shielded ‘blister on the side of the sentencing cell

It is equipped with two master slave manipulators, a viewing window, and a sampling table carrying an array of material sampling equipment.

The table resides on a trolley which can be driven by an air cylinder into and out of the sentencing cell

Continued

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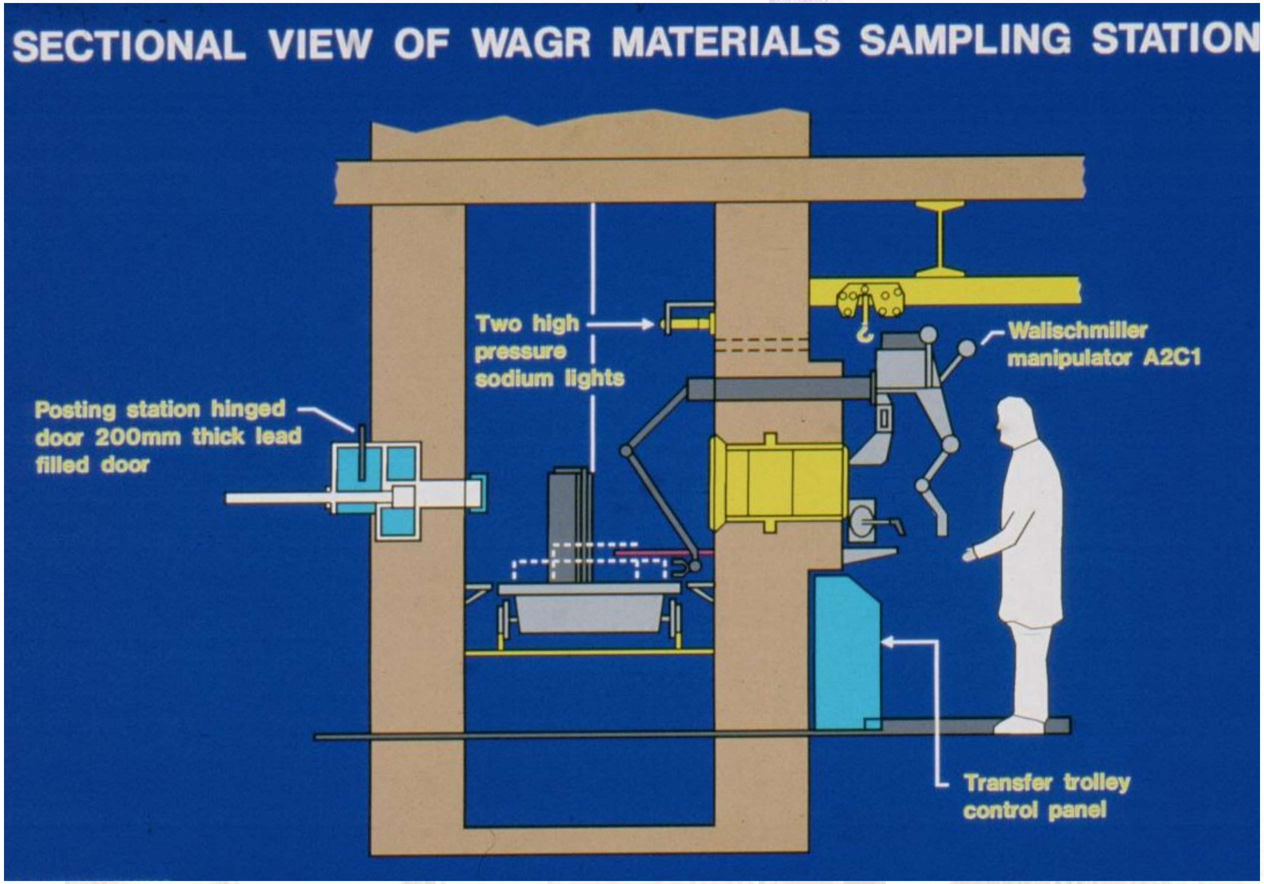
The Material Sampling Station

There is a posting port which can be used to bring new containers into the cell and pass sampled material out of the cell.

The sampling station also has a high resolution gamma spectrometer station and collimator which can be used to provide data on fission product contamination of waste specimens.



Schematic of the sampling station

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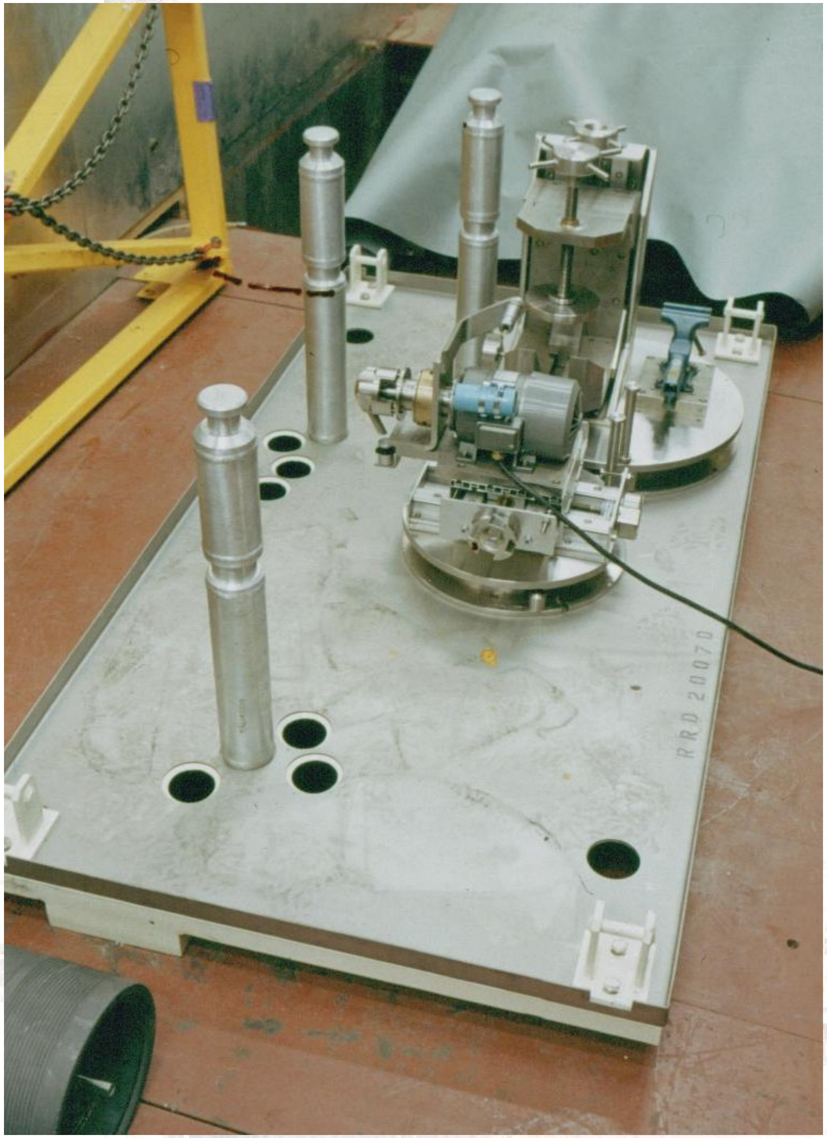
Material sampling station trolley.

Waste items are placed on it in the Sentencing cell using the 3te hoist.

The trolley then travels into the sampling station.

Samples would be put in labelled containers, placed in a lead pot and passed out through the posting port.



Waste Route Lower Loading Cell

- In order to ensure that a waste box would pass the transport requirements with regard to external dose rate when grouted and lidded banks of GM dose rate probes were set in the floor, walls, shield door and ceiling of the of the lower loading cell. Look-up tables were to be provided which would use the un-grouted and un-lidded dose rates to establish whether the regulatory requirements would be met.
- The probes and look-up tables were never actually used – it was found possible to make confirmatory arguments based on the assay method dose rate readings taken in the upper loading cell.
- Also the extended decommissioning programme meant that decay had reduced most items below contentious levels.

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Removal of Heat Exchangers 1994 - 1995

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Heat exchanger still in bioshield being prepared for lift

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Heat exchanger lifted clear of secondary containment

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Heat exchanger being lowered onto transporter vehicle

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Heat exchanger after transportation being lowered into its final resting place at the Drigg LLW repository

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Equipment and Tooling Developed Prior to Handover to the Dismantling Operations Contractor

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The Manipulator

Manipulator Key Features

- 35 kg load capability
- Seven axis electrically powered remotely controlled manipulator.
- Remote operation by two three axis joysticks, one controlling x, y and z translation, the other controlling yaw, pitch and roll.
- Proportional speed control
- 6 degree of offset of tool tip catered for.
- Teach and repeat facility for tool tip trajectories.
- Playback at any tool tip trajectory speed from 0 to 1000mm per sec.

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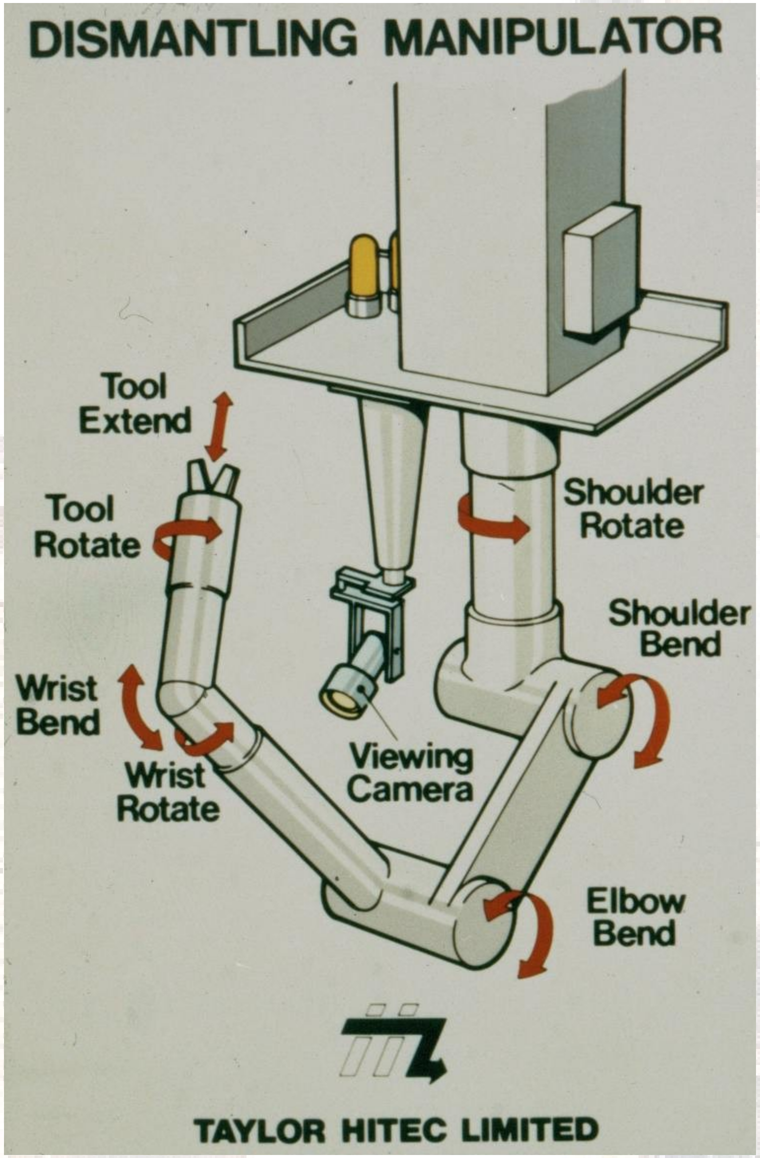
DISMANTLING MANIPULATOR
Tool Extend
Tool Rotate
Shoulder Rotate
Shoulder Bend
Wrist Bend
Wrist Rotate
Viewing Camera
Elbow Bend
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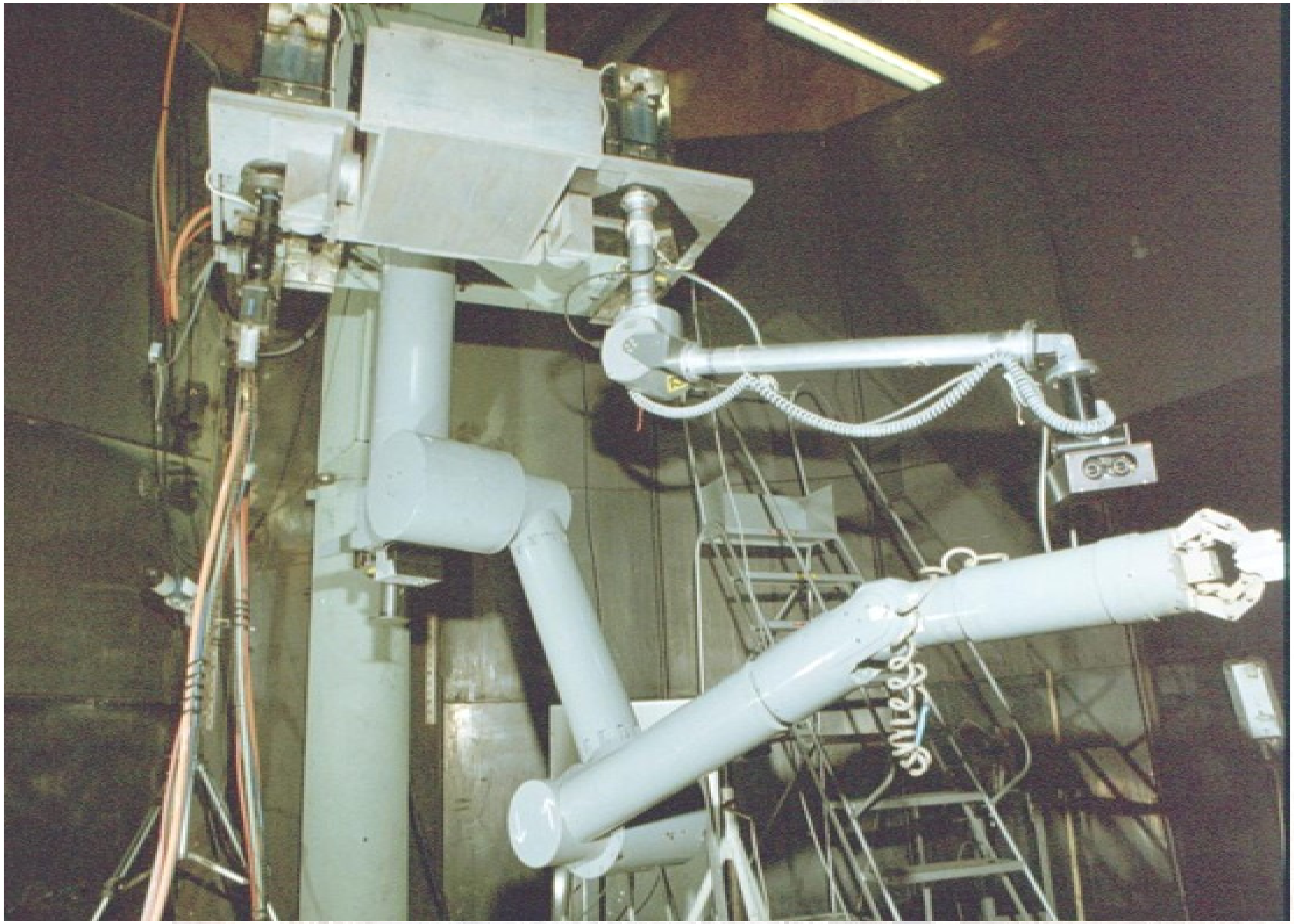

The manipulator in the HERO vault test facility. It is mounted on a simulation of the RDM platform. An early fixed focus stereo camera can be seen on a five axis deployment boom

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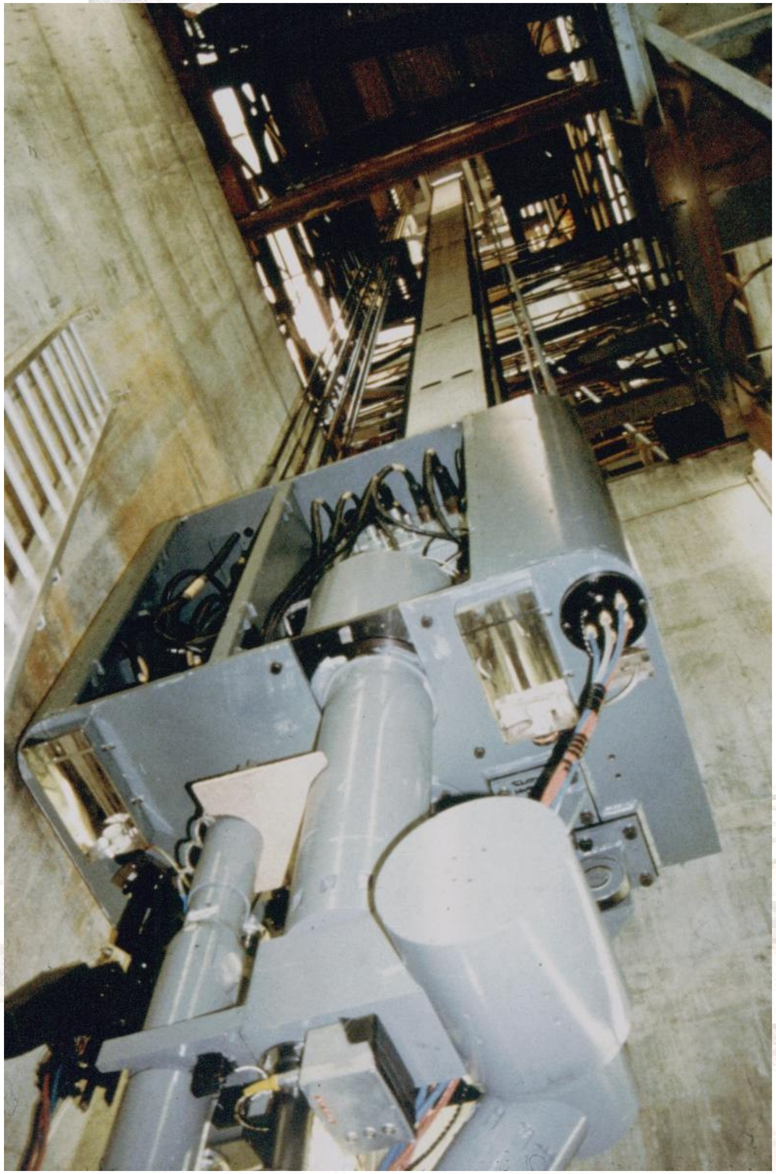
The manipulator mounted on the actual RDM platform. The platform is at the bottom of the fully extended RDM mast. Picture taken during works testing at the Strachan and Henshaw works in Bristol.



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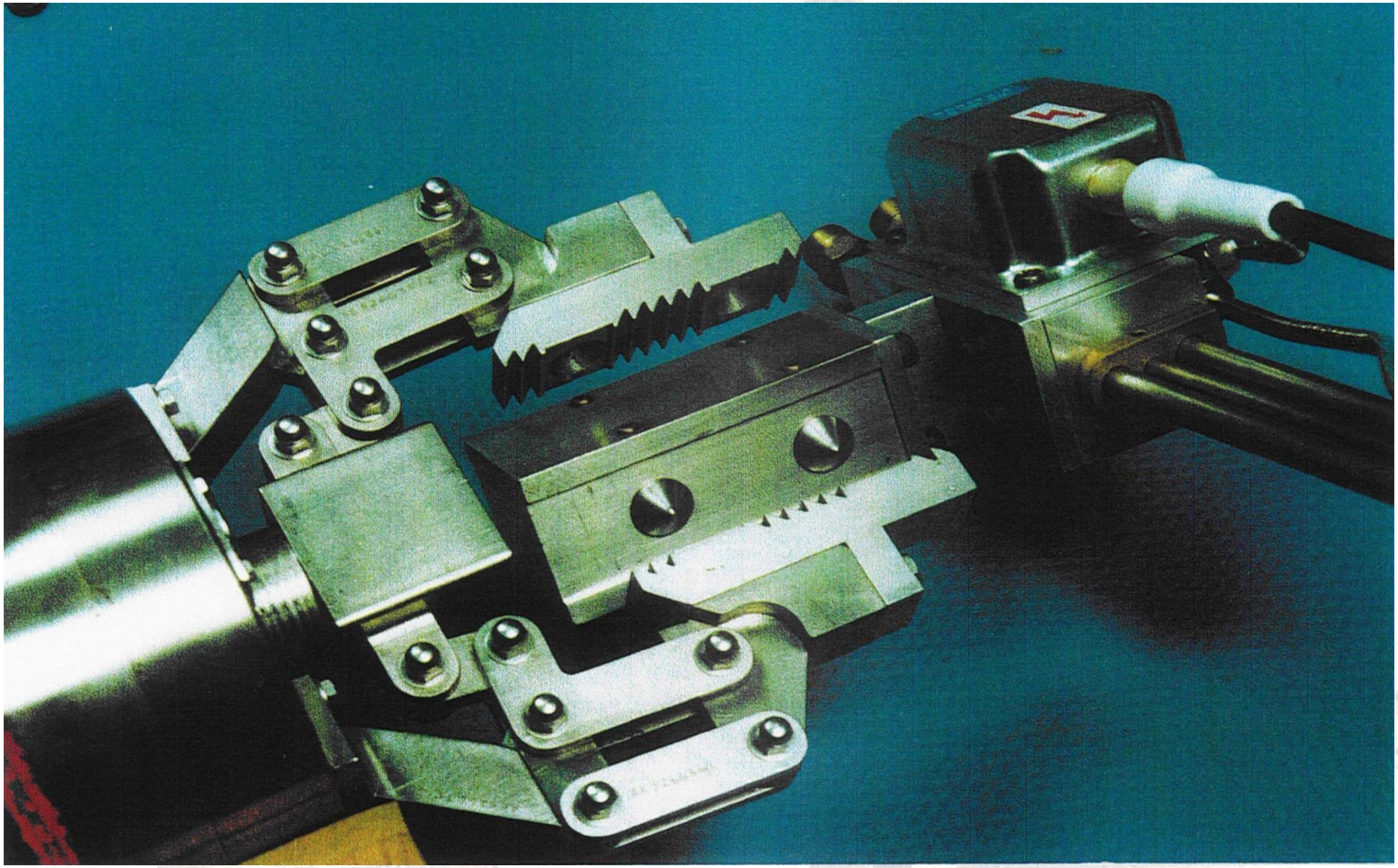

The gripper interface – Coned profiles when used with compliant tooling mountings allow for a degree of misalignment whilst still providing correct engagement

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Viewing systems

1. Black and white radiation tolerant multi-camera system for general viewing in the vault.
2. Initially an orthogonal pair of cameras mounted on a deployment boom was tested for tool operational control. Ideally needed two deployment booms, one for each camera so:
3. A stereoscopic camera mounted on a 5 axis deployment boom was developed along with a viewing system.
4. Flame viewing camera filter systems were developed for use with the oxypropane cutting torches.

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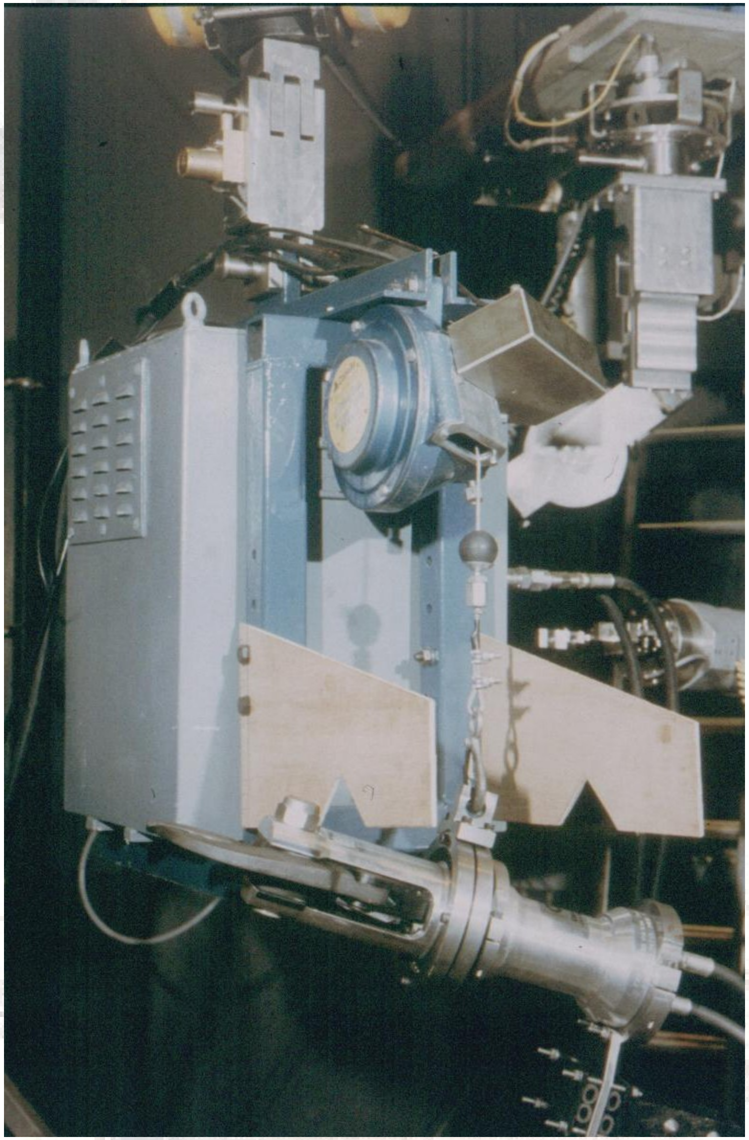
Hydraulic Shear

Hydraulic shear and power pack mounted below platform and deployed using the manipulator via a compliant mount.

The shear unit is suspended neutrally using a constant force reel.

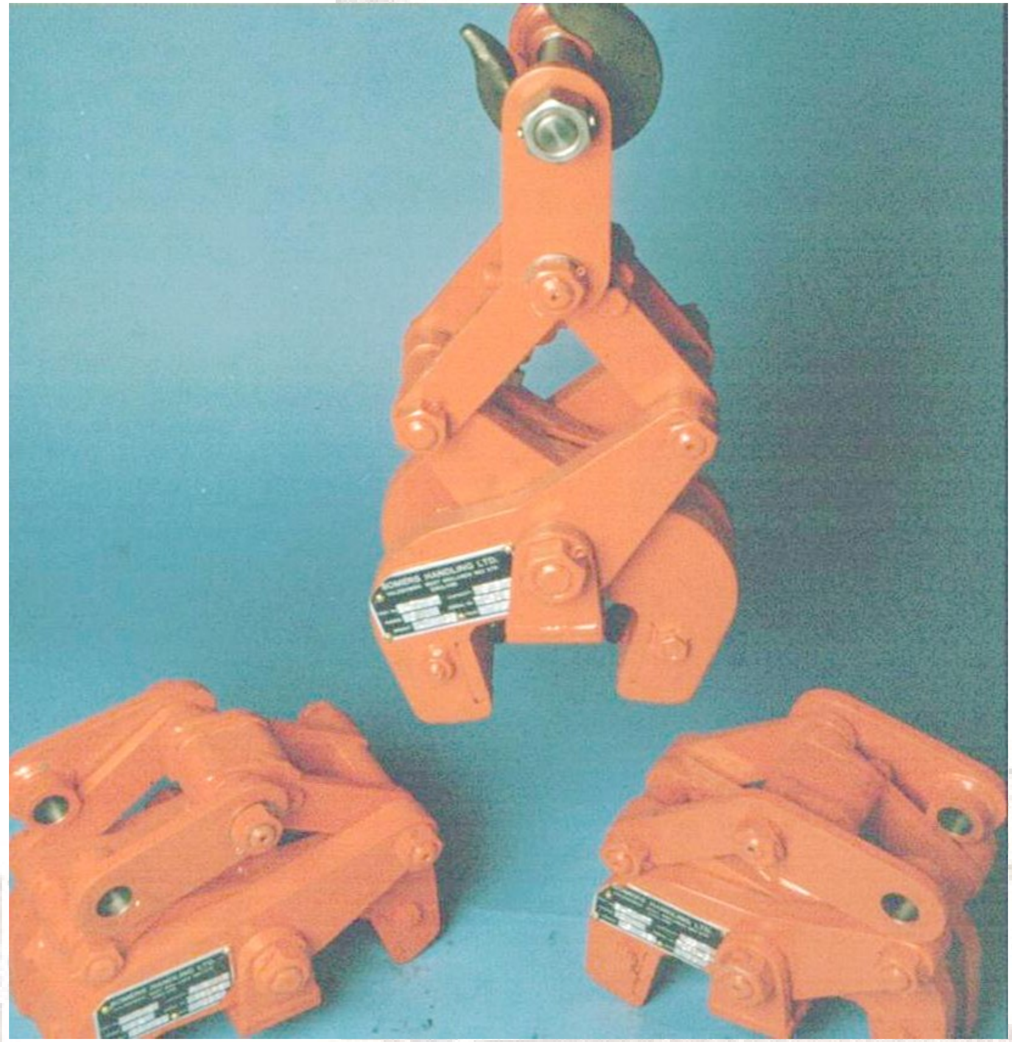
The manipulator places the shear draws around the item to be cut and release its hold prior to the shear being activated.

When the cut is completed the manipulator retrieves the shear.



Sequencing Grabs

Many sequencing grabs were developed to work on different plate thicknesses and also for use externally on tube sections.



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External pipe grab

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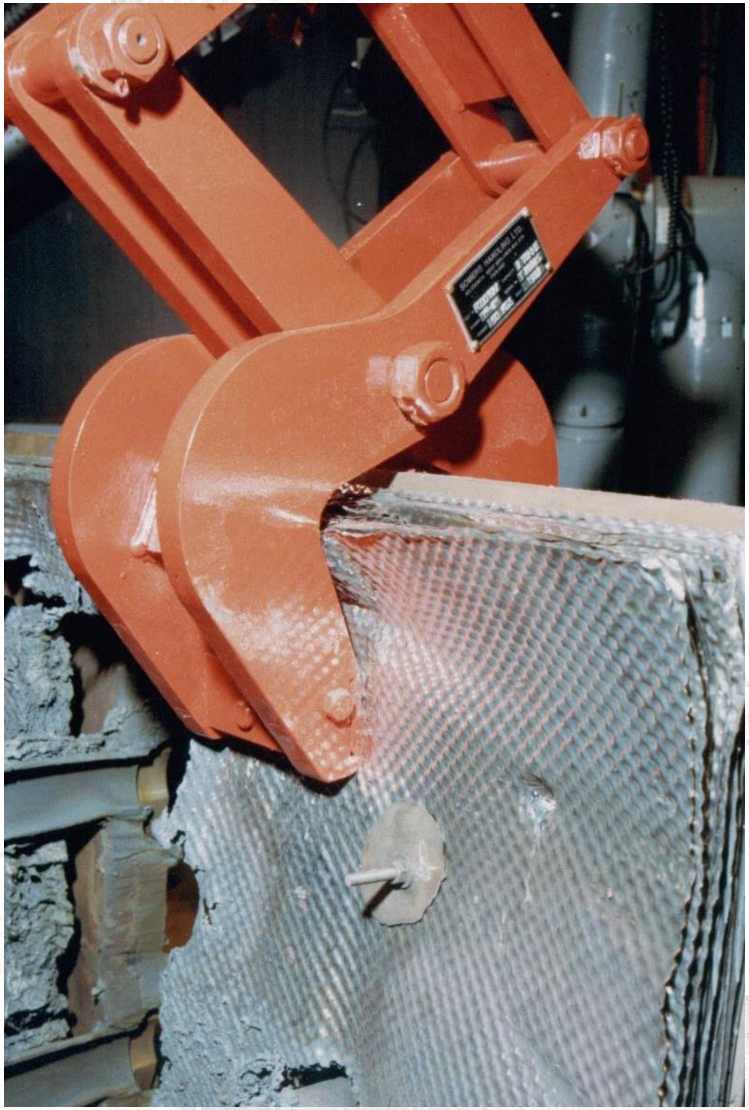
Grab working on plate section lined with multi-layer stainless steel insulation pack.



Vacuum grabs developed for graphite/plate sections

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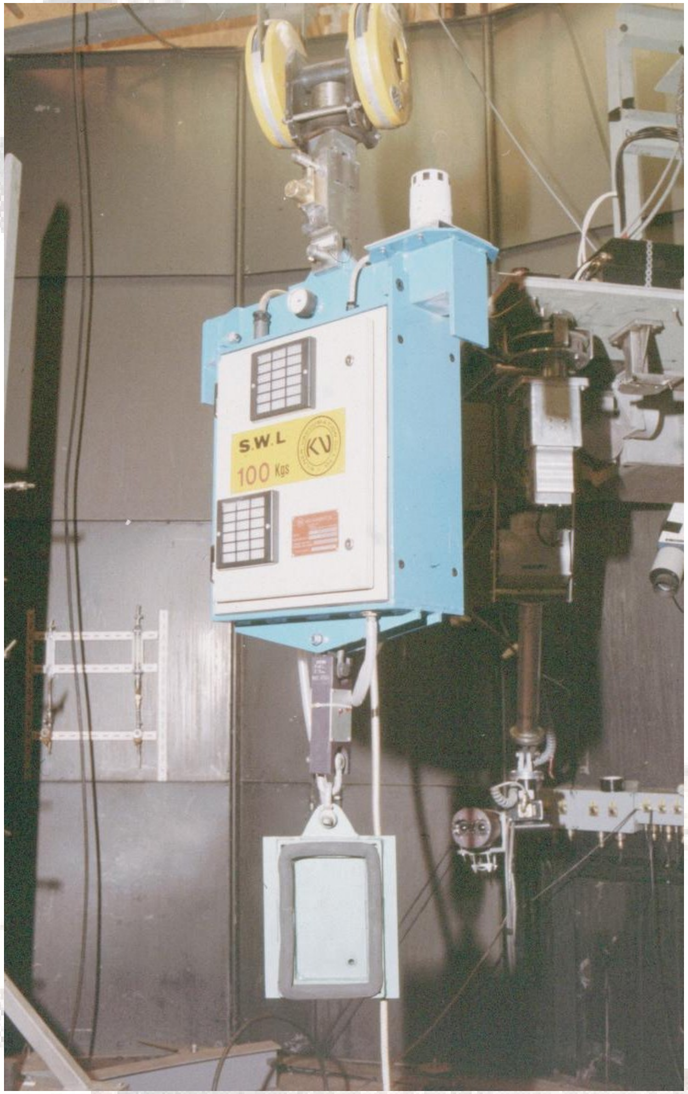
Vacuum grab/pad suspended beneath filtered vacuum power pack

A variety of different shaped pads were developed

Placed using the manipulator using a compliant mount in the gripper.

Clearly visible to the operator when they had taken hold due to the visible movement towards the work-piece as the neoprene skirt ring compressed.



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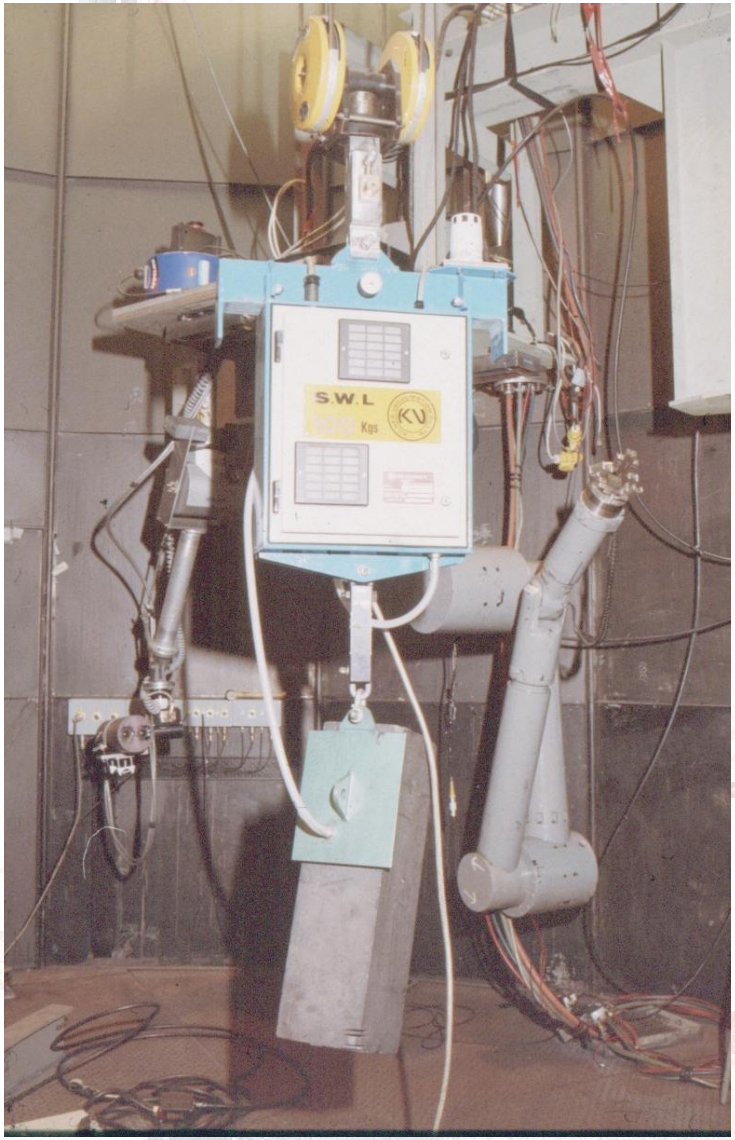
Graphite block suspended in shear using a vacuum pad



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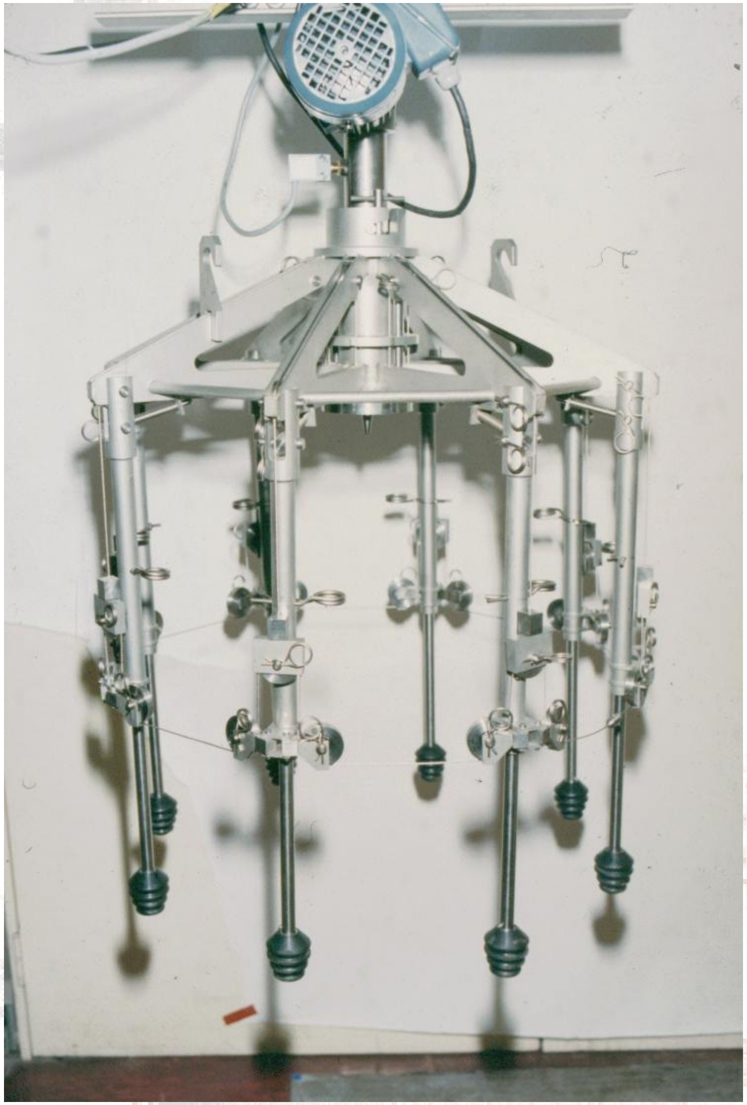
‘Finger’ Grab

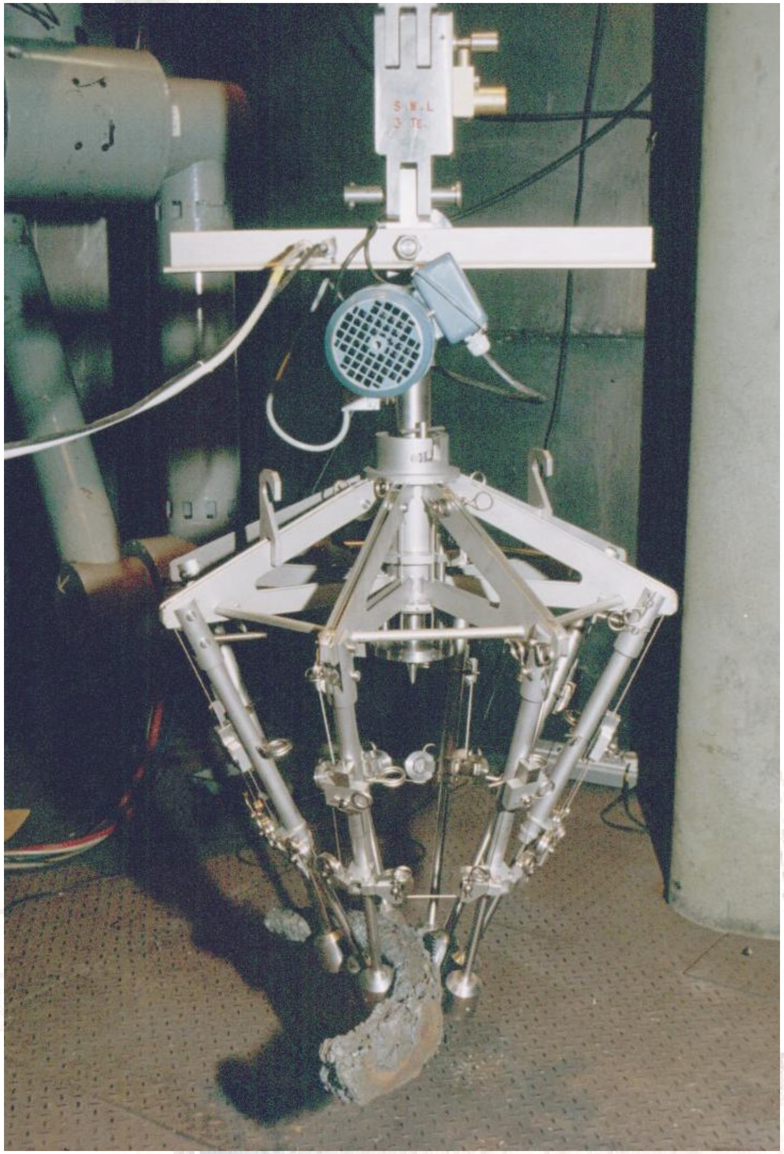
Eight ‘fingered’ grab multi-purpose grab.

Each finger operated by flexible multi strand stainless steel cable.

A range of finger ‘tips’ were available



The finger grab in use



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Magnetic Grabs

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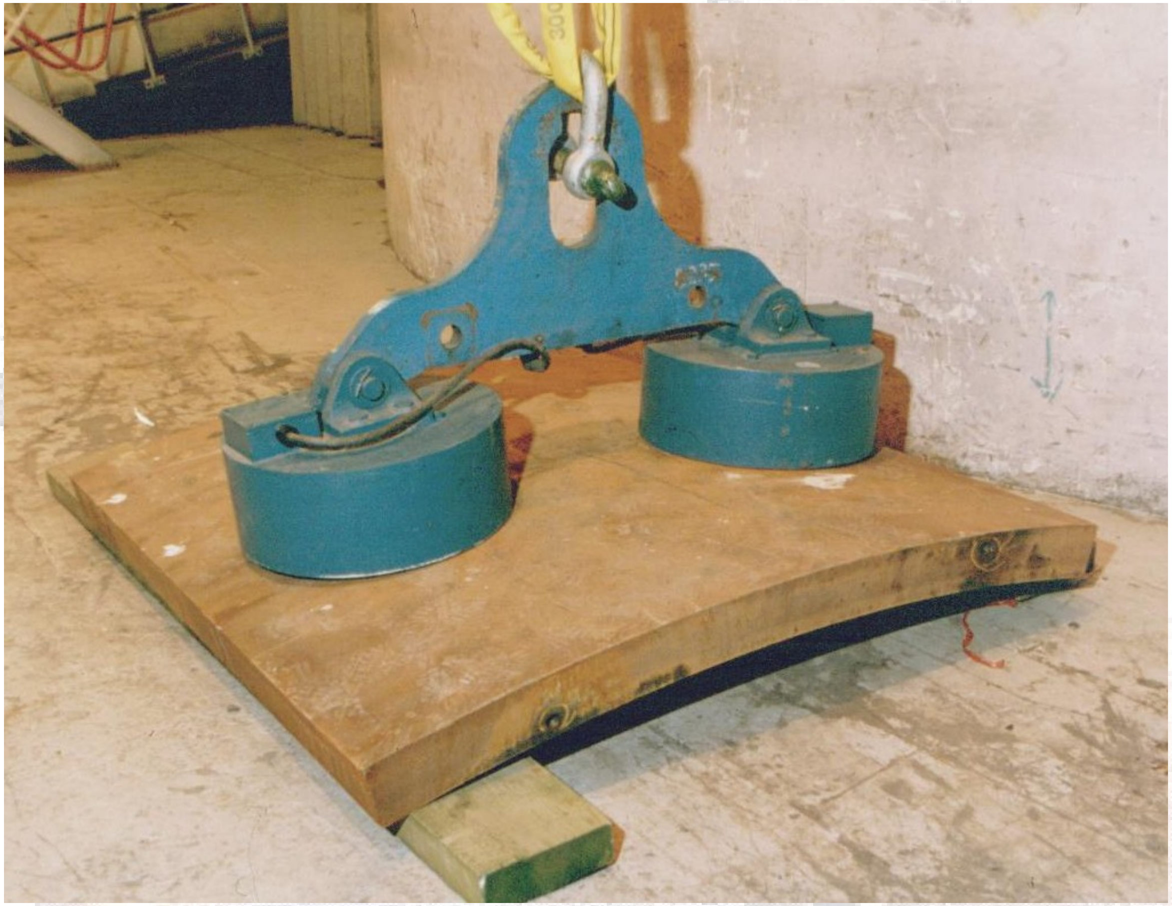
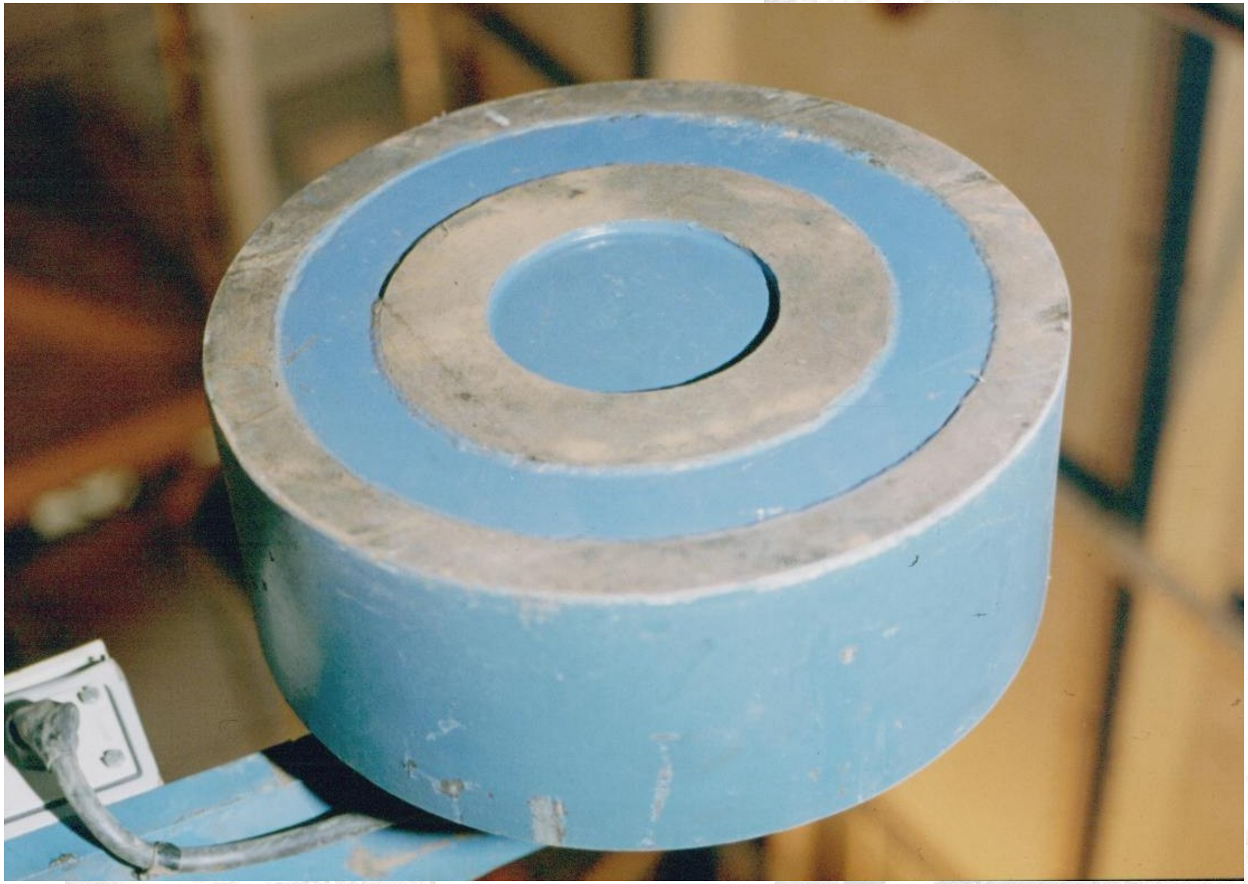


Grab is electrically operated and can be magnetised or de-magnetised at the press of a button



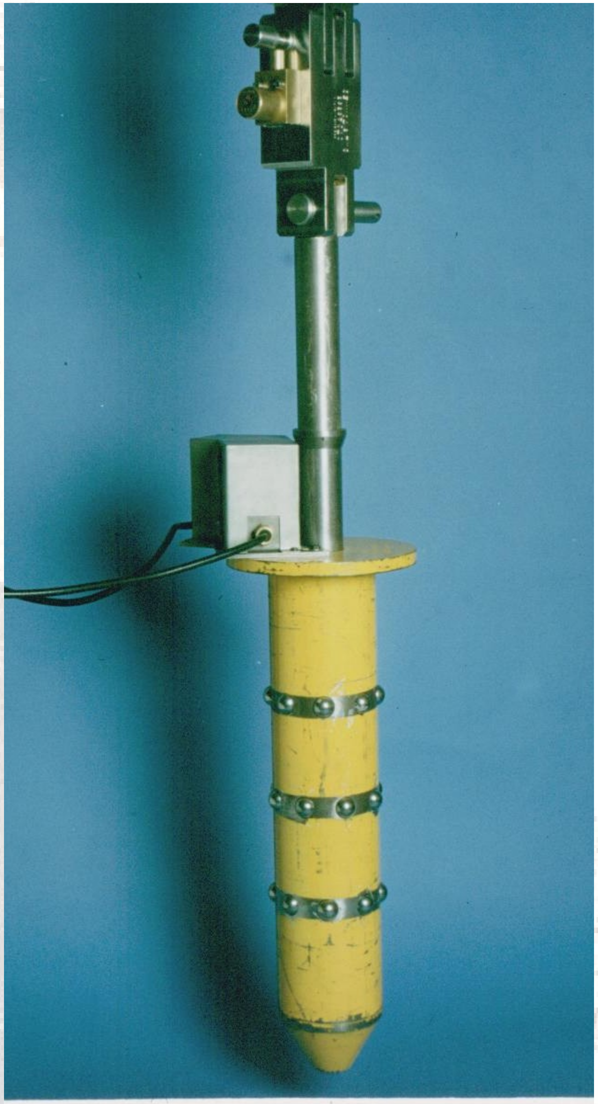
A magnetic grab pole surface

Internal pipe grabs

Pipe internal ball grabs

The first one made was designed for lifting the graphite core bricks out of the core and was exhaustively tested.

Following these successful trials several more were made for lifting the many diameters of steel pipe existing in the reactor.



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The core brick grab lifting a graphite brick.

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Remotely operated oxy-propane torches

Oxypropane torch with iron powder injection about to be used on a simulation of one of the hotbox outlet ducts. Ducts were insulated internally with multiple layers of dimpled stainless steel

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Oxypropane torch about to be used on a simulation of the hot gas manifold top surface

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Methods tested for handling graphite blocks

1. Vacuum grabs (in non active trials reliably lifted masses of ~2/3 atmospheric pressure times pad area.)
2. Internal ball grabs for core bricks with a central hole (excellent)
3. Drilling and tapping and screwing in a lifting feature (eye bolt) (worked well)
4. Using a nail gun to attach a lifting strap (worked well)

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Loop Tube Shear Development

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Loop Tube Shear Development

- There was one recognised complication. WAGR, as an experimental reactor, had six experimental loops which were contained in stainless steel tubes which passed through the reactor core and were totally isolated from the main coolant having their own coolant circuit and heat exchangers.
- The radioactive inventory of these six loops made up more than one third of the total inventory of the reactor.
- It was hence important to remove these and reduce them to a suitable size for packaging in WAGR boxes as smoothly and rapidly as possible.
- A lot of time was spent developing a suitable shear and equipment for raising and clamping the loops sections.

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Loop Tube Shear Development

- During shear development it was found necessary to grout the tubes prior to shearing to ensure a reliable cut.
- Shearing was used because of the very high specific activity of the material of the loops.
- Methods such as sawing or grinding would produce swarf and or small particulate.
- With Co-60 activities of up to 1E9 Bq/g even a few grammes of material in the wrong box would be embarrassing
- High density concrete boxes and high density grout were necessary to keep the external box dose rates within transport regulation requirements
- Even with high density boxes special box furniture was necessary to restrain the tube sections in the inner regions of the boxes prior to grouting to ensure this regulatory compliance.

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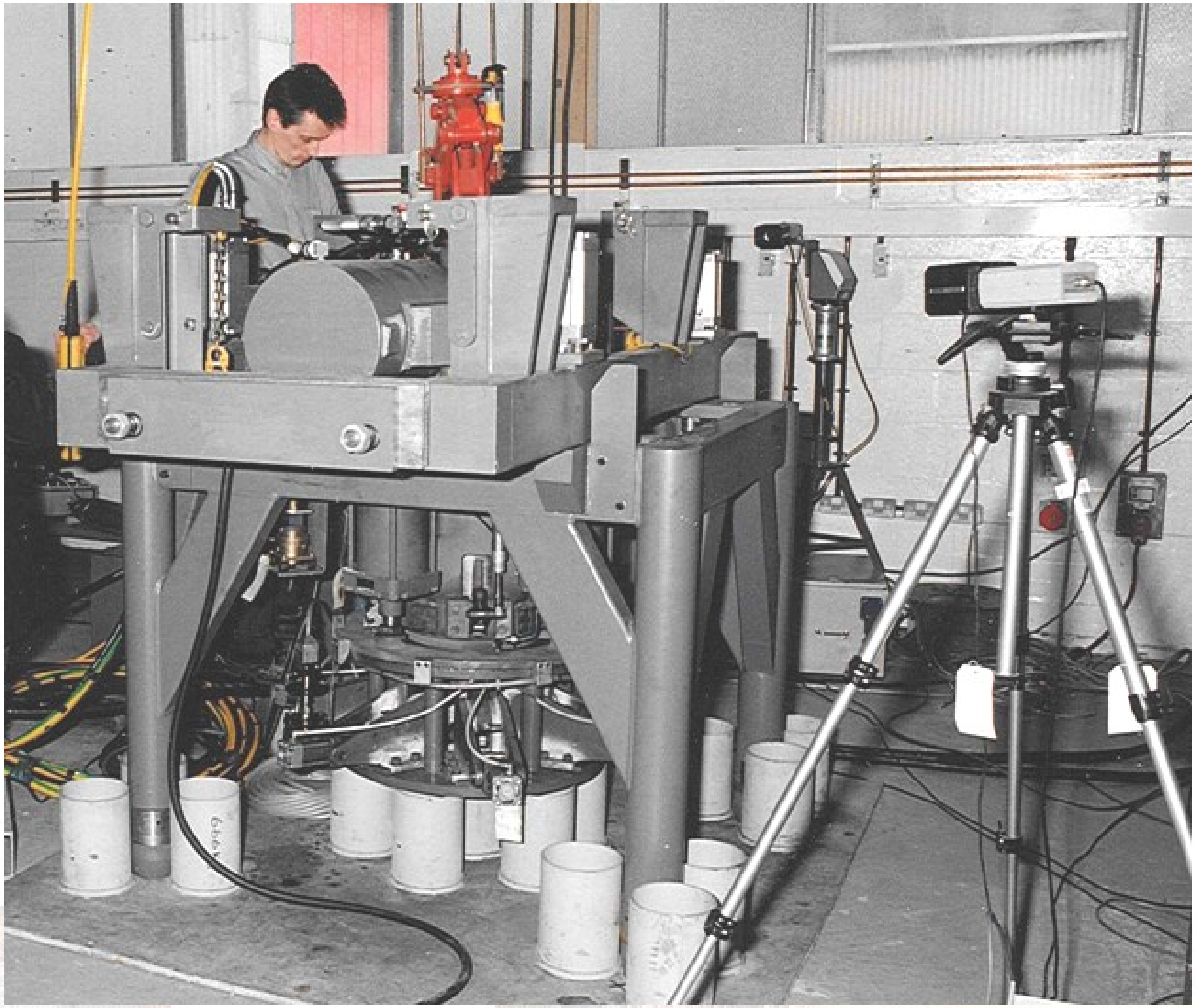
The hydraulic loop shear undergoing testing prior to handover to the operations team



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Lessons learnt

Lessons Learnt

- **Don't assume that something that was easily put together using manual operations can be easily taken apart remotely. It is often like trying to take something apart with one hand that was put together with two. If it is going to work efficiently the whole task needs to be thought through in great detail in advance.**

Lessons Learnt

- It is important to have the people who will be doing the operational work involved in the project at an early stage.
- A lot of the equipment developed was never actually used by the Dismantling Operations Contractor - their team came with their own ideas and experiences with remote handing equipment with which they were familiar and preferred to stay with.

Lessons Learnt

- **Don't change management strategies and policies without careful thought and planning.**

Lessons Learnt

- **Don't throw things away in the name of tidying up which may be important to people carrying out decommissioning. Examples are:**
  - **Operational Documentation - Health Physics surveys, plant condition operational records, as manufactured drawings and details of plant modifications.**
  - **Items like lifting adaptors and specialist tools - they may not seem useful until required.**
  - **Don't decommissiong plant like the re-fuelling machine until you are sure you have no further use for it.**

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Lessons Learnt

- Decommissioning programmes always seem to take much longer than originally intended and even the best equipment breaks down when operated well beyond its design life.
- Try and make sure the equipment is maintainable, and that things like bearings and cabling can be replaced.

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The State of Methods Development for Decommissioning the reactor component parts when the Dismantling Operations Team Took Over

- THE HOT BOX – Lots of thoughts but no firm ideas other than use flame or plasma cutting
- LOOP TUBES – Well thought through as known to be a real problem – grout lift and crop.
- NEUTRON SHIELD – Can't be difficult just use the reverse of construction.
- TOP REFLECTOR, CORE ABD SIDE REFLECTORS< BOTTOM REFLECTOR – Just a few thermocouples and pipes to crop - working grabs developed – should be easy,
- THERMAL SHIELD – Just remove fish plates and lift composite slabs free. Just a few thermocouples and tubes to make it difficult

Continued

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The State of Methods Development for Decommissioning the reactor component parts when the Dismantling Operations Team Took Over

- CORE SUPPORT STRUCTURES – Flame cut with manipulator and lift free, as long as a stable sequence can be found.
- PRESSURE VESSEL AND INSULATION – Lots of thoughts and ideas, but nothing that was at all certain to work.

As you can see there was still a large amount of work on methods of dismantling left to be done when he took over with the plant down to the hot box level.

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